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Yellowpoplar: Reaction to Crown Release and Other Factors Influencing Growth

WEST VIRGINIA UNIVERSITY AGRICULTURAL EXPERIMENT STATION

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By Torkel Holsoe

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Introduction

In the past most research in silviculture and forest management has dealt with the growth of stands composed of various forest tree species on different sites. Through permanent sample plots we have obtained a more or less complete knowledge of the growth of stands, their rate of production, and the amount of products that can be harvested from them at rotation age. Complete information has been furnished by Møller (21) who has constructed tables for four to six site indices for beech (*Fagus silvatica* L.), oak (*Quercus robur* L.), and Norway Spruce (*Picea abies* Karst.) in Denmark. These give for average Danish thinnings the relationship between age and total height, current annual growth, average annual cut, basal area, volume diameter breast high (d.b.h.), and number of trees per hectare. These tables give a complete guide for management of stands after site index has been determined.

In this country some sample plots have been established in different forest cover types giving the current annual growth of various species. Since no standard treatments of the stands have been determined, such as have been developed through more than a hundred years of management in the European forests, these sample plots have not given any accurate directives for treatment of the stands to obtain different dimensions in certain lengths of time.

Although it may be possible in pure stands to give rather specific directions about volume to be removed and frequency of thinnings, such as has been done in Europe, this still does not indicate to the forester which tree he should select for cutting and which tree he should leave. Although guides are extremely helpful in predicting the development of the entire stand, they do not help the forester in his choice of trees when marking for thinning. In this country where many of the stands are mixtures of up to ten or fifteen valuable species, an intimate knowledge of not only the individual species but also of the individual tree is necessary. Before making the choice of cutting or leaving a tree, the forester should know what will happen if he does one or the other. He should know what the reaction will be on the tree that is left if he cuts one, two, or three trees that are interfering with its crown development. Most research in silviculture and forest management has not helped the practicing forester much in the work on which he spends a great deal of his time—namely, developing, through some form of cutting, the individual trees that form the forest stands.

The first step in this direction came more than a hundred years ago, when Reventlow, (25), studied the forms of trees throughout

their different stages of development. Reventlow indicated that European beech should grow up in partial shade and in fairly dense stands whereby it would develop a certain amount of clear length. After this had been obtained, the tree should be given space for continued crown expansion. This would develop a deep and rounded crown and maintain a relatively fast diameter growth. These thoughts, however, were forgotten during the following years when the German influence in silviculture and forest management was governing. The thoughts during that time were almost entirely focused on entire stands and the production per area unit. The individual tree was forgotten.

Not until Biolley (1) showed interest in the uneven-aged and mixed stands managed under the selection system did the development of the individual tree come to the forefront. Later foresters such as Mundt (10) in Denmark expanded on the work of Biolley and applied the selection system. This helped re-establish interest in the individual tree instead of more or less pure stands of beech. Later studies by Heck (11), Busse (5), and Macon (18), without too much success tried to relate various crown dimensions with diameter growth. The interest in the growth of the individual tree, however, had been awakened.

In recent studies on red oak (*Quercus borealis* Michx.) and white ash (*Fraxinus americana* L.) in New England (13), and yellowpoplar (*Liriodendron tulipifera* L.) in West Virginia (14), it was found that a highly significant relationship existed between basal area growth and various crown dimensions such as crown diameter, crown length, and crown surface. It also was shown for yellowpoplar (14) that at an age of 100 years, using the arbitrary value of 100 for the first 16-foot log, the second log has a value of 59.5, whereas the third log is worth only 42.5 compared to the value of the first log. Therefore, it was recommended that as soon as the first two 16-foot logs were included in the dead length, it would be advantageous to maintain as much live crown on the trees as possible to encourage fast diameter growth.

In line with these recommendations, the question arises, What will be the reaction on trees that have been released in various degrees? Since it has been established that the basal area growth is closely related to the size of the crown, it will be of interest to know if light releases will have different effects on the trees than more or less complete release. If the latter is possible, it would be feasible, by heavy thinnings, to create good growing conditions for the remaining trees through a profitable operation and thereby make thinnings in more or less inaccessible areas that have been neglected because thinning operations, according to conventional methods, could not be made at a profit because of the small volume removed in each cutting.

Purpose of Experiment

Since the amount of material removed in each thinning is closely related to the economics of such an operation, and since the forester marking for thinning is constantly confronted with the question of how much crop trees should be released, this experiment was established to study the reaction of various degrees of release on individual, remaining trees.

By releasing the crowns of dominant, codominant, and intermediate trees in various degrees at times both before and during the growing season, it was hoped to furnish practicing foresters with answers that would help them in their timber management work. In this country, where cuttings take place throughout the year, it may be expected that released trees might react differently, depending on the season in which the release occurs. To investigate this, it was decided to release some of the sample trees during the dormant season and others during the growing season. It may be expected that if the crown of a tree receives a more or less complete release during the growing season, many of the shade leaves on the lower part of the crown or in other shaded places might be damaged by the sudden increase in light intensity and thereby cause a reduction in growth. Because of this, it was decided to investigate the cell structure from week to week during the beginning of the growing season. The summer release was not to be made until the cell structure of the leaves had become fixed.

Earlier Studies and Related Investigations

Most European foresters have advocated that thinnings should be light and made frequently since, otherwise, the remaining trees will receive a shock that will retard their growth for some years. Although this theory has been employed as a standard operating procedure in European forestry, it does not seem to have been based on investigations. Few references in the literature can be found relating to this shock effect after heavy thinnings. Juncker (16) stated that "it is important to make the shock of liberation as small as possible on the standing trees so that they will fill in the space immediately." In other cases where the shock reaction has been mentioned, special reference has been made to particular soil types. For example Bornebusch (3) stated that "too sudden and severe release in forest stands, particularly on heavy and moist clay soils, may have damaging effect which will show up as drying out of the upper crown. In such cases the heavy thinning will cause the height growth to slow up." This same phenomenon

has been observed in this country by Jensen and MacAloney (15). They stated that "during the second growing season after about half of the volume of a yellow birch and paper birch stand was removed, decadence became evident in the tops of yellow birch. Water sprouts were noted on almost half the yellow birch in the treated area. . . In spite of indications of decadence following logging, a cutting of this type stimulated the growth rate of residual yellow birch over the 15-year period following cutting. . . At the end of the 15-year period, the water sprouts along the lower part of the bole had disappeared and those near the original crown had developed into a part of the new crown."

In contrast to this, Wadsworth (27) described the reaction of suppressed and intermediate ponderosa pine (*Pinus ponderosa* Laws.) that received complete release from competition. He stated that "the effect of release upon diameter growth was pronounced." The trees that were released completely grew an average of 2.2 inches on diameter breast high during the ten years following release, compared to .6 inches during the decade before release.

Through recent work on red oak and white ash in New England (13) and yellowpoplar in West Virginia (14), determinations were made on the effect of different crown dimensions on basal area growth. These studies also have shown the development from sapling to mature size of the individual tree that will produce the greatest amount of clear wood outside the knotty core in the most economical way. The measurements were taken on trees of different sizes. This indicates that such development is possible if the trees are given adequate space. In order to obtain accurate results, however, it will be necessary to measure the development of the individual tree and its reaction to different amounts of crown release rather than to make comparisons between different trees. Such studies have not been made, probably because it would be necessary to have very accurate measuring devices or to wait for several years before measurements could be taken with conventional instruments.

Through the introduction of micrometer measurements of radial growth, as brought out by Reineke (24), Daubenmire (7), and Brown, Rose, and Spurr (4), it is now possible to measure radial growth of trees with an accuracy of .001 inch. A micro-dendrometer has been fashioned by attaching a micrometer permanently to a block of hard-wood to which also is fastened a metal plate with a glass covering. The metal plate is framed along part of the edge with a metal shield. A standard dial gauge micrometer, manufactured by the B. C. Ames Company of Waltham, Massachusetts, or by L. S. Starrett Company,

Athol, Massachusetts, is used. The spindle of the micrometer is placed perpendicularly to the glass plate. On the trees to be investigated, three round-headed brass screws about three inches long are screwed through the bark into the wood, so that they are well anchored in the wood. The position of the screws is such that the line between the upper two is horizontal. The distance between these two screws is a little less than the width of the glass plate of the micro-dendrometer. All screws are placed perpendicularly to the surface of the tree so they will form continuations of radii. The third screw is between the upper two screws and approximately three inches below the line between them. The micro-dendrometer is placed so that the upper screws rest on the glass plate against the frame shielding the upper edge of the glass plate, and in such a way that one of the upper screws hits the corner of the shield. The spindle will then touch the bark in the same place each time measurements are taken. This can be seen in Figures 1, 2, and 3. On this particular place, the bark is smoothed down, and a small glass plate ¾ by ¾ inch is glued to the bark. The screws will keep their position because the tree will grow out over them, but the glass plate will change its position relative to the heads of the screws, for it will move with the bark. Therefore, by means of the

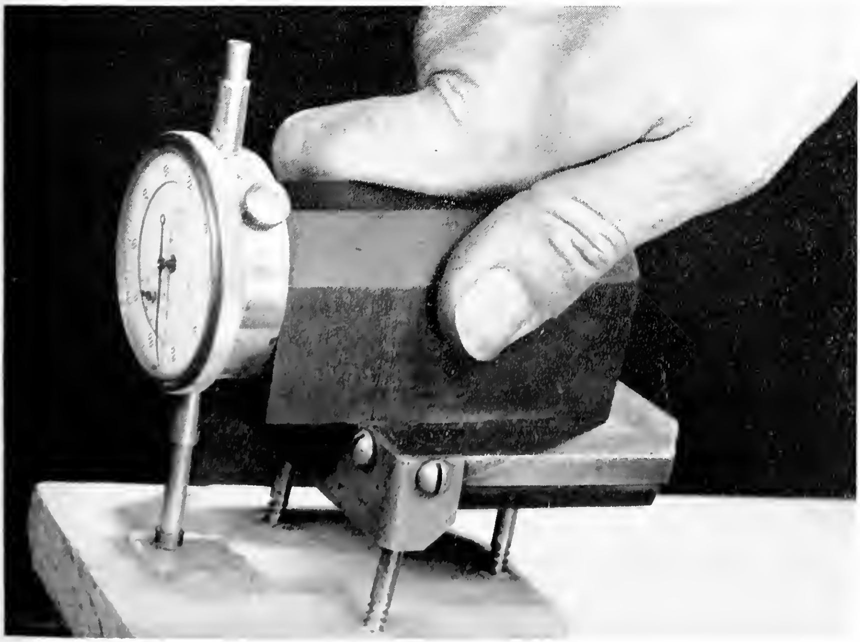

Figure 1. Micro-dendrometer on check board.

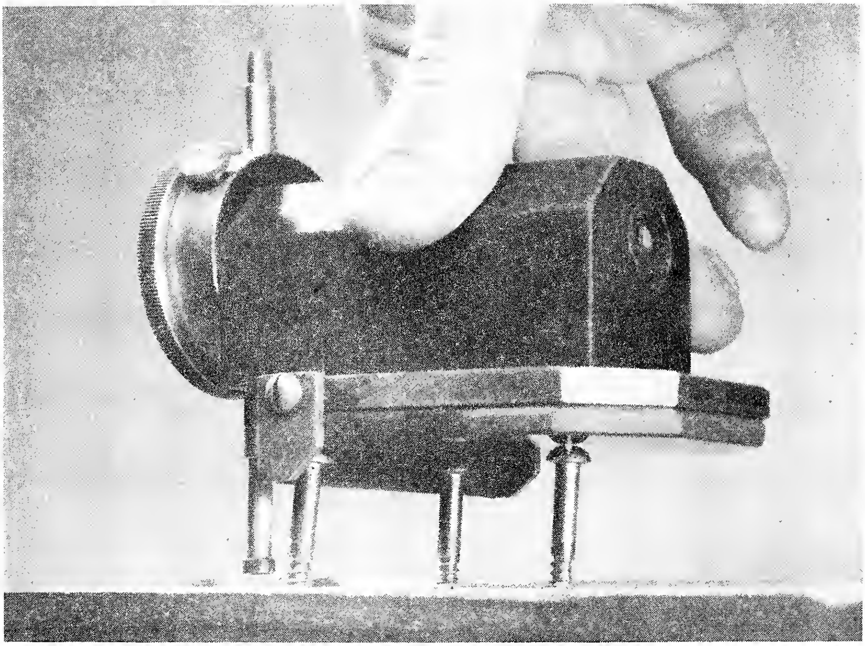

FIGURE 2. Micro-dendrometer on check board.

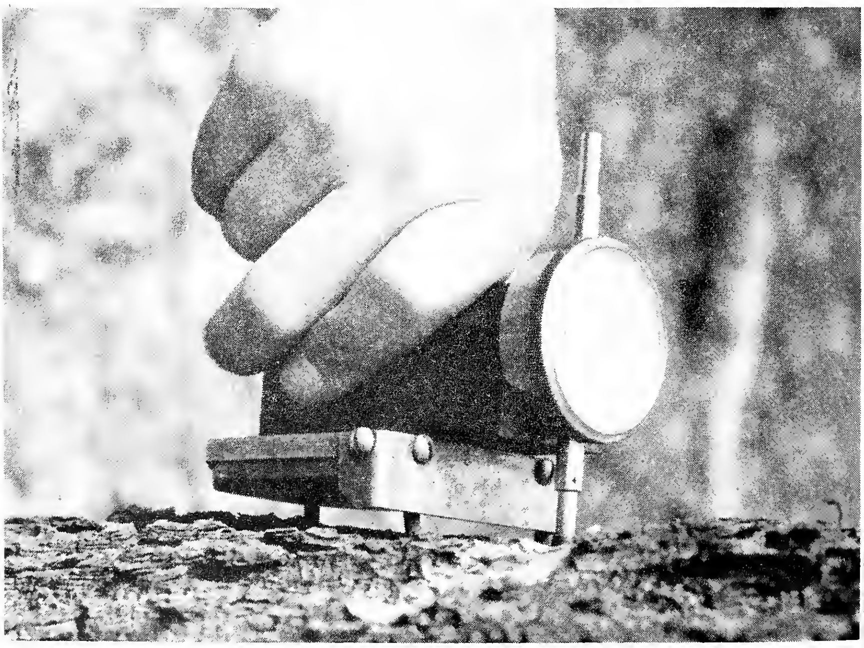

FIGURE 3. Micro-dendrometer on tree station.

micro-dendrometer it is possible to measure the difference in position between the glass plate and the heads of the screws.

Since only one instrument is necessary to take numerous measurements, and since it is possible to have as many stations on the individual tree as the diameter will allow, this instrument is extremely important in silvicultural research. Measurements can be made rapidly with an accuracy of .001 inch. In the present experiment, with one man taking the measurements and one man recording, it was possible to average 150 measurements per hour.

Stephens and Spurr (26) used a micro-dendrometer to investigate the daily growth before and after crown release in red pine (*Pinus resinosa* Sol.). They found that an increased rate of growth could be observed within twenty-four hours after the trees were released. By measuring trees on which dendrometer stations were established both morning and evening, these investigators found the daily variation in the radial dimensions of trees. The radial growth curve has a saw-toothed shape, since the trees expand at night but contract during the day. The difference between the expansion and the contraction constitutes the daily growth. In that experiment, however, no measurements were taken regarding the extent to which the remaining trees were released.

Establishment of Experiment

The experimental area used was situated on a farm woods owned by West Virginia University. The area, about forty acres, is approximately two miles north of Morgantown, West Virginia, on latitude 39 degrees 40 minutes north, and longitude 79 degrees 56 minutes west. The forest cover type is generally yellowpoplar-white oak-red oak (10). The yellowpoplar is predominating in many places.

Yellowpoplar was chosen for this investigation because this species is fairly intolerant, and therefore is rather sensitive to sudden changes in light intensity. Furthermore, yellowpoplar is one of the most important timber species in the Appalachian region. Large areas of almost pure stands of even-aged yellowpoplar of high density are found throughout the Appalachian region. These stands are in great need of thinning, even to the extent that many have completely stagnated. Since many of them are situated in rather inaccessible places, however, they cannot be thinned profitably unless a considerable volume is removed in each cutting.

During January and February, 1949, the trees to be used in the experiment were selected. They ranged in diameter breast high from

6.4 inches to 26.1 inches. To investigate the influence of release on as wide a range of conditions as possible, intermediate, codominant, and dominant trees were selected. The trees were numbered. A letter was assigned to each tree to indicate whether it was to be a control tree or to be released. A total of 193 trees was selected for the experiment, and 51 were designated as controls. Of the 193 trees, 50 were of the dominant crown class, whereas 119 were codominant, and 24 were intermediate. The composition of the stand made it impossible to include more intermediate trees in the experiment.

Dendrometer stations were established on all the trees to be used in the experiment. On each of the control trees, stations were placed in such a way that they faced the cardinal compass directions. On the first control tree the station faced north, the second east, third south, fourth west. On the trees to be released there were established from two to five stations. These were placed so that if the tree were to be released from one side by the removal of a neighboring tree, a station was placed facing this tree and another one was placed on the diametrically opposite side. If the tree was to be released by the removal of several surrounding trees, stations were placed so that they faced all released sides. In addition, one station was placed on a neutral side.

The dendrometer stations were established, as earlier described, in conformity with the findings of Brown, Rose, and Spurr (4). The micro-dendrometer used in this experiment varied from the one mentioned by these research workers in that the wooden block that holds the micrometer was extended about an inch. Thus the spindle was removed the same distance from the metal shield. This was done so that the spindle could be placed farther away from the screws and thereby prevent possible callus formation around the screws from influencing the measurements. By trial it was found that a rubber compound cement was the best lasting glue to keep the glass plates on the trees in position during the entire growing season. The glass plates, on which the spindle of the micrometer rests, were placed 4½ feet above the ground representing measuring height. At the same time, the diameter breast high of the sample trees was measured with a diameter tape to the nearest tenth of an inch.

No thinnings or cuttings had been made during the eight previous years in the vicinity of the sample trees at the time the experiment was started, and no release of the sample trees was made during the 1949 growing season. Therefore, the growth factors would be somewhat similar to what they had been during the years previous to the establishment of the experiment.

Procedure

A. Measurements of Sample Trees

The measurements of radial growth of the yellowpoplar trees were first taken on April 30, 1949, when the buds started to swell and some bud scales had begun to open. The measurements were taken each Saturday morning between 8:30 and 11 o'clock. The trees were examined in the same sequence so that each dendrometer station was measured at about the same time of day. Each morning before the micro-dendrometer was used, the reading was checked against a station established on a well-dried board kept in the office. At the end of each series of measurements, the micro-dendrometer was again checked to see if any changes had occurred in the adjustment of the instrument. The measurements of each station were recorded with an accuracy of five ten-thousandths of an inch on a prepared sheet, as shown in Figure 4. By the end of September no more growth was recorded on any of the dendrometer stations. The measurements were discontinued until the following spring.

During the winter of 1949-50, all of the dendrometer stations used for the previous summer's work were examined. In some instances callus formation had developed around the screws. Since it was feared that this formation might continue during the following growing season, and thereby influence the growth under the glass plate, it was deemed advisable to move the stations. To compensate for any error, every other station was moved up six inches and the others were moved down six inches. Later analyses showed that this movement of stations had no significance in recording radial growth. At the end of the experiment it also was found that the fear of the callus formation influencing the growth under the glass plate was not justified. By the end of the second growing season it was noticed that the callus from the screw holes did not extend more than one-half inch out from these. Since the glass plate never was closer than one and one-half inches to any of the screws, the callus formation could not have influenced the position of the glass plate.

Comprehensive measurements of all the 193 sample trees were taken during the dormant season. Total height, clear length, and dead length were measured to the nearest foot with an Abney level. Clear length was defined as the height from the ground to the first dead branch, whereas dead length was determined as the height from the ground to the first live branch. Crown length was measured from the top of the tree to the level of the widest part of the crown, or to the branch tips of the lowest live branches. If the crown was irregular,

MICRO-DENDROMETER EXPERIMENT

Date: April 30, 1949. Time: 9:07 – 12:55 Weather: Sunny – dry

Check	.2535	24.a	.3550	51.b	.5330	72.a	.4590	93.b	.6820	118.c	.6260	144	.5220
P.1	.6480	24.b	.3215	52.a	.5630	72.b	.5220	93.c	.6890	118.d	.6590	145.a	.4485
P.2	.4350	25.a	.3930	52.b	.5720	73.a	.5540	93.d	.5920	119	.6110	145.b	.4815
P.3	.4540	25.b	.5170	53.a	.3960	73.b	.5530	94.a	.6860	120.a	.5740	146.a	.6560
P.4	.4635	26.a	.4275	53.b	.5000	74.a	.5250	94.b	.5460	120.b	.5155	146.b	.5690
P.5	.4635	26.b	.4310	53.c	.4425	74.b	.5800	95.a	.6590	121.a	.5505	147.a	.6480
P.6	.6390	27.a	.4520	53.d	.5760	74.c	.5310	95.b	.5035	121.b	.5010	147.b	.7045
1	.5520	27.b	.3900	54.a	.4195	74.d	.5580	96.a	.6130	122.a	.5930	148.a	.5250
2.a	.4650	28.a	.3990	54.b	.4305	75.a	.5080	96.b	.5610	122.b	.5360	148.b	.5500
2.b	.4235	28.b	.4185	55.a	.4050	75.b	.5565	97.a	.4950	123	.6340	148.c	.6305
3.a	.6490	29.a	.4090	55.b	.4040	76.a	.5670	97.b	.5140	124	.5795	148.d	.7170
3.b	.5930	29.b	.4635	55.c	.3590	76.b	.5770	98.a	.5550	125.a	.6420	149	.5740
4.a	.6230	30.a	.3325	55.d	.5400	77.a	.5080	98.b	.5320	125.b	.4930	150	.5350
5	.5515	30.b	.4140	55.e	.4480	77.b	.4425	99	.6385	126	.6015	151	.5510
6.a	.5435	31.a	.5790	56.a	.4630	78.a	.5440	100.a	.5290	127.a	.4640	152	.5280
6.b	.5190	31.b	.4430	56.b	.4130	78.b	.6135	100.b	.5410	127.b	.5660	153.a	.6030
7.a	.5155	32	.4050	57.a	.4075	78.c	.5460	101	.4900	128.a	.6095	153.b	.5880
7.b	.7120	33.a	.4680	57.b	.3035	78.d	.6150	102.a	.4510	128.b	.5745	154.a	.6420
8.a	.6215	33.b	.5000	58	.3965	79	.5260	102.b	.6350	129	.5250	154.b	.3885
8.b	.5800	34.a	.3850	59.a	.3320	80	.4370	103	.4870	130.a	.6100	155	.5850
9	.6585	34.b	.4450	59.b	.4015	81.a	.5255	104.a	.5800	130.b	.5170	156.a	.7165
10.a	.5645	35.a	.5470	59.c	.3385	81.b	.6120	104.b	.5715	130.c	.5230	156.b	.6540
10.b	.5280	35.b	.4920	59.d	.3575	82.a	.4365	105.a	.4770	130.d	.5430	156.c	.6385
11.a	.4420	36	.5035	59.e	.4480	82.b	.4975	105.b	.4365	131.a	.5615	156.d	.5565
11.b	.4040	37	.5275	60.a	.5715	83.a	.6150	105.c	.5640	131.b	.5800	157.a	.5990
12.a	.5830	38.a	.4400	60.b	.4485	83.b	.5640	105.d	.4400	132.a	.5530	157.b	.5240
12.b	.4060	38.b	.6080	61.a	.5210	83.c	.5745	106	.4420	132.b	—	157.c	.4590
13.a	.4910	39	.5260	61.b	.4405	83.d	.5560	107.a	.3475	133.a	.5565	157.d	.4925
13.b	.5310	40	.4350	62.a	.4280	84.a	.5350	107.b	.4300	133.b	.4150	158.a	.3870
13.c	.4670	41	.5290	62.b	.5625	84.b	.5210	108.a	.4440	134	.4535	158.b	.5670
13.d	.6550	42	.5440	63.a	.5850	85.a	.6205	108.b	.4900	135	.4750	159.a	.5095
14.a	.5230	43	.3840	63.b	.5130	85.b	.6190	109.a	.4010	136.a	.5265	159.b	.6460
14.b	.5425	44	.5680	64	.4840	86.a	.6370	109.b	.4720	136.b	.5980	160.a	.5890
15.a	.5475	45.a	.4600	65	.5245	86.b	.5080	110.a	.4810	137.a	.6075	160.b	.5900
15.b	.5660	45.b	.5340	66	.5325	87.a	.4815	110.b	.4610	137.b	.5225	161.a	.6720
16	.6415	46.a	.4905	67a	.5830	87.b	.5050	111.a	.4350	138	.6220	161.b	.6160
17	.5140	46.b	.4480	67.b	.4905	88.a	.5895	111.b	.5030	139	.4245	161.c	.6120
18.a	.4360	46.c	.4680	68.a	.5640	88.b	.6280	112.a	.6260	140.a	.4400	161.d	.6630
18.b	.4515	46.d	.4390	68.b	.3905	89.a	.6570	112.b	.5925	140.b	.6485	162.a	.3340
19	.5575	47.a	.5320	69.a	.4500	89.b	.5410	113	.4880	141.a	.5000	162.b	.6660
20	.4760	47.b	.6085	69.b	.5695	90.a	.6210	114	.5615	141.b	.4890	163.a	.5570
21.a	.4395	48.a	.4075	70.a	.5055	90.b	.7155	115.a	.5570	142.a	.5620	163.b	.5420
21.b	.4755	48.b	.4320	70.b	.5880	91.a	.6440	115.b	.5860	142.b	.5200	164	.7655
22.a	.3805	49.a	.5080	70.c	.5425	91.b	.6775	116	.5160	142.c	.4195	165	.5910
22.b	.3425	49.b	.4355	70.d	.6075	92.a	.5735	117	.5495	142.d	.4790	166.a	.6640
23.a	.3940	50	.5480	71.a	.4340	92.b	.6620	118.a	.5135	143.a	.6110	166.b	.7460
23.b	.4430	51.a	.5460	71.b	.4890	93.a	.6215	118.b	.5150	143.b	.6440	167.a	.4865

FIGURE 4. Field recording sheet for weekly measurements.

an average value was determined. Diameter breast high was measured to a tenth of an inch with a diameter tape. To calculate the average crown diameter, the crown projection was mapped. This was done by placing a plane table inside the crown projection. An alidade was fashioned from an engineer's scale to which a small metal piece with

an eye at the zero point was attached. This scale was fastened to the plane table. It was used to sight along, and at the same time offset, the measured dimensions. A steel tape was fastened on the ground exactly below the zero point of the alidade. By following the outline of the crown and calling off the distances, it was possible to draw in the crown projection directly on the plane table. Besides projecting the crown of the sample tree, all neighboring tree crowns touching or interfering with the crown of the sample tree were projected and drawn in on the sketch. This can be seen in Figure 5. With an Abney level the heights of interference of all neighboring crowns were recorded. By converting the area of the crown projection to a circle with the same area, the average crown diameter was determined.

By means of the formula for the surface of a paraboloid:

$$A = \frac{\pi r}{6h^2} (4h^2 + r^2)^{3/2} - r^3 \qquad \text{(A)}$$

where r is equal to half the crown diameter and h is equal to the crown length, the surface of the crown was calculated.

The surface of interference was determined by the formula for the parabola:

$$A = 2/3\,ab \qquad \text{(B)}$$

where a was the height of interference and b was the projected extent of interference between the two crowns.

According to the outline of the project, it was planned to release half of the sample trees, except the 51 control trees, during the dormant season. The other half were to be released during the growing season. The plan also called for releasing the trees according to the circumference of the crown by quarters. From the crown projection of the sample trees and their neighbor trees, it was determined in the office which trees should be cut in order to give them the prescribed amount of release. The cutting for the release was completed during March, 1950.

The measurements were started on April 29, 1950, when the buds started to break.

The second release took place during the third and fourth weeks in June, or during the eighth week of the growing season.

B. Determination of the Time at Which Light and Shade Leaves Are Formed

As soon as the leaves opened after the growing season started, leaves from exposed and shady positions were collected. Slides were

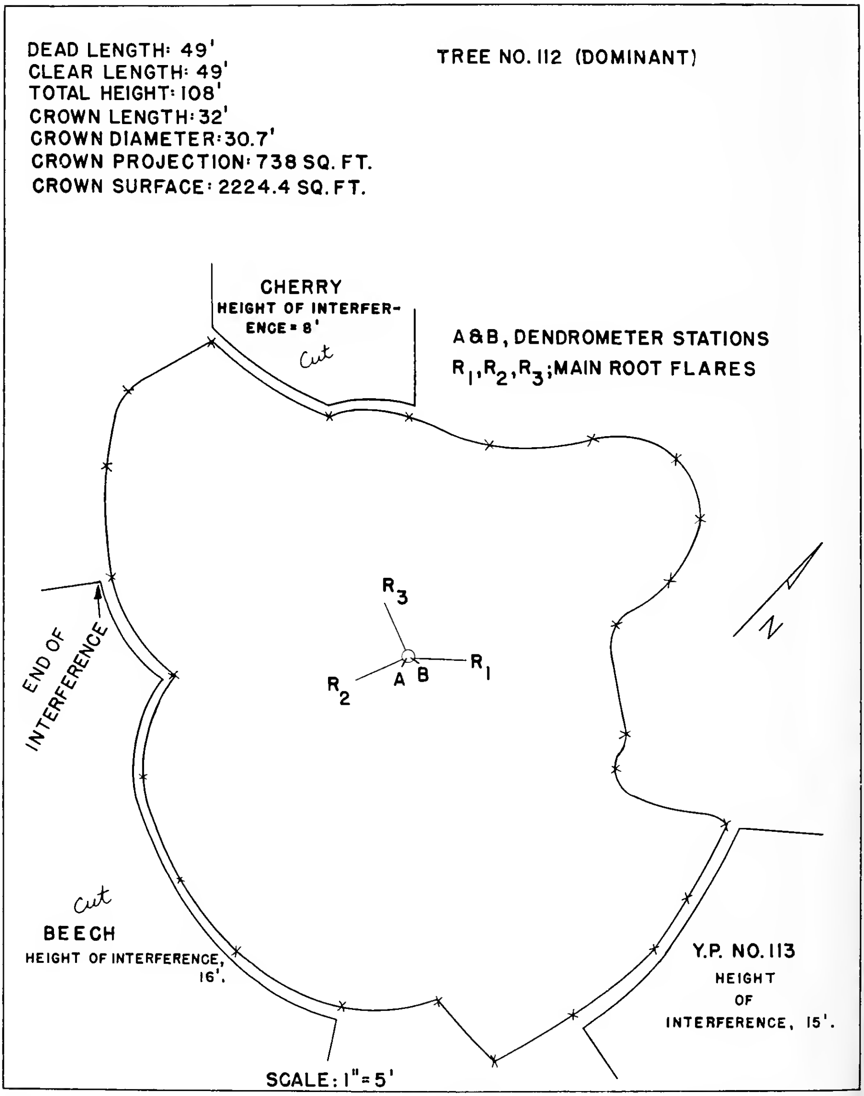

FIGURE 5. Projections of crowns of sample tree and neighboring trees.

prepared from these leaves to determine the development of the cells, particularly the palisade cells. During the first week in May the cell structure of light and shade leaves was the same. The first indication of a difference between the two kinds of leaves showed up in the latter part of May, or during the third and fourth weeks after the growing season started. It can be assumed that during the first weeks the cell construction is about the same on all the leaves, since the leaf

cover is still light and, therefore, will not create too much shade on the lower placed leaves. Later, when the shade on the lower leaves becomes denser, the differentiation between light and shade leaves takes place. During the fourth week of the growing season, palisade cells appeared on the light leaves. In the beginning only one layer of palisade cells was present, but at the beginning of June, or after the leaves had been out for about five weeks, a second layer of palisade cells showed up. By the middle of June no further change in the cell structure took place on either the light or the shade trees. To be sure that no more change took place in cell structure in the leaves, the release of the rest of the trees was delayed until the latter part of June, or after the seventh week of the growing season had been completed.

In conjunction with the release of trees, the question arises as to when the foundation of the leaf structure is determined. This has been mentioned by research workers in plant physiologly. Eames and MacDaniels (8) stated that "the number of palisade layers and the density of the cell structure depends largely, either directly or indirectly, upon the light intensity." Clements (6) suggested that "palisade cells are usually converted into sponge cells in the shade and sponge cells into palisade cells in the sun." Furthermore, Clements stated that "sun species transferred to the shade usually change much or all of their palisade tissue into sponge." The foregoing authors do not state if the cell structure of the leaves is already determined in the bud formed the previous growing season, or if the change takes place after the new leaves come out. This question is brought out by Müller (23) who stated on page 212 (translated from Danish): "As far as trees and bushes are concerned, the formation of shade and light leaves depends on the light intensity to which the branch is exposed during the year the bud is formed."

Since this question would be of importance in explaining any shock reaction of the trees during the first year of growth after a heavy release, it was decided to investigate this matter further. During the 1949 growing season a group of yellowpoplar reproduction (about four feet high) was located. The trees in this group grew in dense shade. This had caused their height growth to be retarded so that the average was about four to five inches. Leaf samples were collected from these trees, and examination showed that all the leaves had only sponge cells and no palisade cells. During the winter of 1949-50, four of these trees were transplanted to an open area in the vicinity with the same general exposure and site. Leaves were collected during the summer of 1950 from these plants and from the trees that remained

in the shade on the same area from which the first plants had been taken. Figures 6 and 7 show the cell structure of these leaves. It is evident that no palisade cells are present in Figure 6, which shows a typical leaf from the trees that remained in the shade. Figure 7 shows a typical leaf from the trees transplanted from the shade during the winter into an open space. All leaves collected from these transplanted trees showed the same cell structure. Therefore, it seems that the leaf structure is not determined by the "light intensity to which the branch is exposed during the year the bud is formed" as stated by Müller (23), but is determined by the light intensity under which the new leaf opens during the first seven weeks of the growing season.

C. Preparation of Growth Data

As soon as the growth data from the dendrometer stations were obtained from the field, these figures were transferred to the forms shown in Figures 8, 9, and 10. Under "Corrected Measurements" were placed the readings obtained with the micro-dendrometer after they were corrected for the differences that occurred while checking the instrument before using it on each day of measurement. The figure listed above this column is a new base figure that was used after July 15 when an adjustment was made on the instrument. The next two columns are self-explanatory. These three columns were filled out for each measuring station on each tree. On tree No. 112, the crown projection of which is shown, there were two stations. The accumulated diameter growth was averaged and used in Figure 10, which gives the data for the tree. On the basis of diameter breast high measurement that was made before the growing season started, the diameter dimension for each week of the growing season was recorded. These measurements were made to .01 inch. Basal area tables to .01 inch (Appendix) were constructed. From these the basal area was found. The last column gives the accumulated basal area growth in square feet.

Basal area growth is used in all discussions about growth, since it was found (13) that this unit has a closer relationship to crown development than does straight diameter growth. Figure 11 shows the relationship between crown surface in square feet and basal area growth for 1949 in square feet for 193 yellowpoplar trees. The correlation index for this curve is .966, which is considered highly significant. This checks very well with the relationship found in an earlier study for red oak and white ash (13), in which the relationship between crown surface and last ten years basal growth was used.

FIGURE 6. Microscopic cross section of shade leaf.

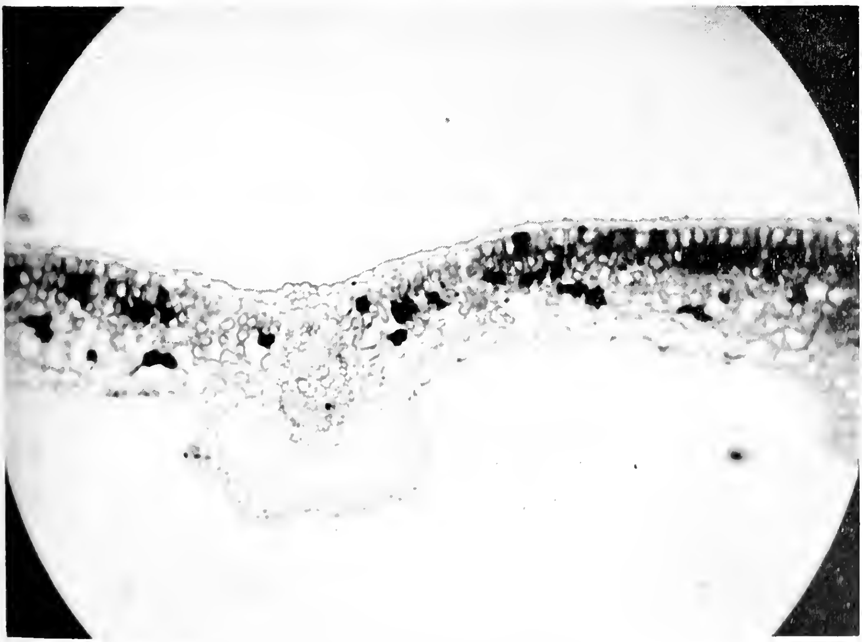

FIGURE 7. Microscopic cross section of light leaf.

Tree Number 112 Species Yellowpoplar D.B.H. Oct. '49 ____ Oct. '50 ____ May '50 ____ Diam. Growth ____

Station: A

Total Height ______
Crown Diam. ______
Dead Length ______
Clear Length ______

New base figure to be used below line: .5460

4/29/50 Check Meas: ______

Dates	Corrected Measurements	Accumulative Radial Growth	Accumulative Diam. Crowth	Diam. Dimension	Basal Area
4/29/50	.5340	—	—		
5/6/50	.5360	.0020	.0040		
5/13/50	.5380	.0040	.0080		
5/20/50	.5430	.0090	.0180		
5/27/50	.5515	.0175	.0350		
6/3/50	.5670	.0330	.0660		
6/10/50	.5825	.0485	.0970		
6/17/50	.6000	.0660	.1320		
6/24/50	.6180	.0840	.1680		
7/1/50	.6250	.0910	.1820		
7/8/50	.6590	.1250	.2500		
7/15/50	.6825	.1485	.2970		
7/22/50	.7180	.1720	.3440		
7/29/50	.7240	.1780	.3560		
8/5/50	.7690	.2230	.4460		
8/12/50	.7890	.2430	.4860		
8/19/50	.8045	.2585	.5170		
8/26/50	.8150	.2690	.5380		
9/2/50	.8270	.2810	.5620		
9/9/50	.8290	.2830	.5660		
9/16/50	.8350	.2890	.5780		
9/23/50	.8360	.2900	.5800		

FIGURE 8. Calculation sheet for individual station (Tree No. 112, Station A).

Tree Number 112 Species Yellowpoplar D.B.H. Oct. '50 ____ May '50 ____ Diam. Growth ____

Oct. '49
Total Height ______
Crown Diam. ______
Dead Length ______
Clear Length ______

Station: B

New base figure to be used below line: .5060 4/29/50 Check Meas: ______

Dates	Corrected Measurements	Accumulative Radial Growth	Accumulative Diam. Growth	Diam. Dimension	Basal Area
4/29/50	.4940	—	—		
5/6/50	.5020	.0080	.0160		
5/13/50	.5055	.0115	.0230		
5/20/50	.5120	.0180	.0360		
5/27/50	.5260	.0320	.0640		
6/3/50	.5390	.0450	.0900		
6/10/50	.5770	.0830	.1660		
6/17/50	.6000	.1060	.2120		
6/24/50	.6150	.1210	.2420		
7/1/50	.6420	.1480	.2960		
7/8/50	.6710	.1770	.3540		
7/15/50	.6970	.2030	.4060		
7/22/50	.7400	.2340	.4680		
7/29/50	.7680	.2620	.5240		
8/5/50	.7970	.2910	.5820		
8/12/50	.8205	.3145	.6290		
8/19/50	.8410	.3350	.6700		
8/26/50	.8450	.3390	.6780		
9/2/50	.8700	.3640	.7280		
9/9/50	.8730	.3670	.7340		
9/16/50	.8800	.3740	.7480		
9/23/50	.8830	.3770	.7540		

FIGURE 9. Calculation sheet for individual station (Tree No. 112, Station B).

Tree Number 112 Species Yellowpoplar D.B.H. Oct. '50 20.6
May '50 19.9
Station: A & B Diam. Growth .7

4/29/50 Check Meas: .2705

Oct. '49
Total Height 108'
Crown Diam. 30.7'
Dead Length 49'
Clear Length 49'
Crown Length 32'

Dates	Corrected Measurements	Accumulative Radial Growth	Accumulative Diam. Growth	Diam. Dimension	Basal Area Sq.Ft.	Accumulative Basal Area Growth Sq. Ft.
4/29/50			-----	19.90	2.1598	.0000
5/6/50			.0100	19.91	2.1620	.0022
5/13/50			.0155	19.92	2.1642	.0044
5/20/50			.0270	19.93	2.1668	.0070
5/27/50			.0495	19.95	2.1707	.0109
6/3/50			.0780	19.98	2.1772	.0174
6/10/50			.1220	20.02	2.1860	.0262
6/17/50			.1720	20.07	2.1969	.0371
6/24/50			.2050	20.10	2.2035	.0437
7/1/50			.2390	20.14	2.2123	.0525
7/8/50			.3020	20.20	2.2255	.0657
7/15/50			.3516	20.25	2.2365	.0767
7/22/50			.4060	20.31	2.2498	.0900
7/29/50			.4400	20.34	2.2564	.0966
8/5/50			.5140	20.41	2.2770	.1172
8/12/50			.5545	20.45	2.2809	.1211
8/19/50			.5935	20.49	2.2898	.1300
8/26/50			.6080	20.51	2.2943	.1345
9/2/50			.6450	20.55	2.3032	.1434
9/9/50			.6500	20.55	2.3032	.1434
9/16/50			.6630	20.56	2.3055	.1457
9/23/50			.6670	20.57	2.3077	.1479

FIGURE 10. Calculation sheet for average values of all stations.

Observations Made During the Experiment

A. Differences in Radial Growth on the Individual Trees During First Week of the Growing Season

On May 7, 1949, when the measurements at the end of the first week of the growing season were taken, it was noted that some of the trees showed no growth on one station, whereas another station on the same tree would have grown as much as .0025 inch.

Measurements from 18 trees, each of which had four dendrometer stations placed in the cardinal compass directions, showed the following

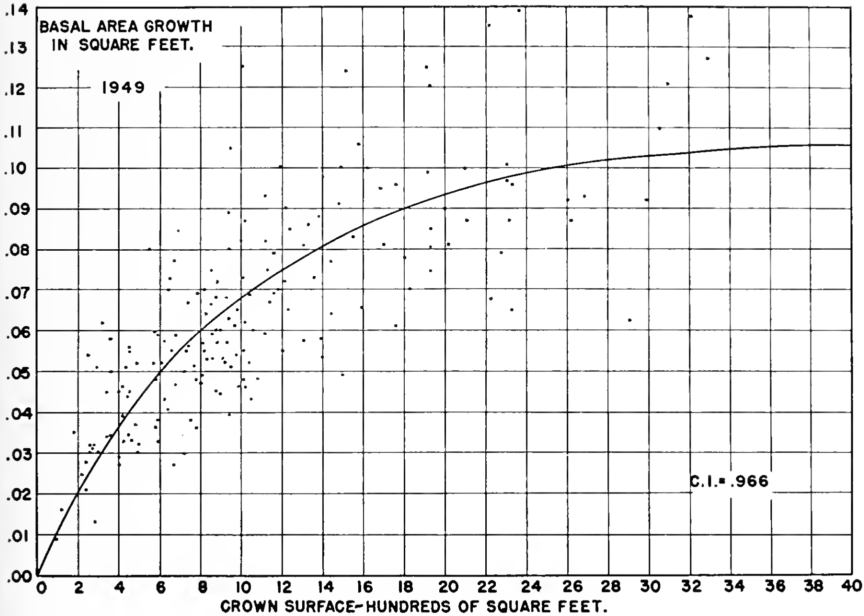

FIGURE 11. Relationship between crown surface and basal area growth for 193 trees.

average growth in inches by the end of the first week of the growing season:

North	South	East	West
.00219	.00325	.00228	.00247

From these measurements it can be seen that the south side of the trees grew considerably faster than any other side. After the south side in rate of growth comes the west side, and then the east and north sides. This seems logical, because the south side will be warmest, after which the west side will receive more heat than the east or the north sides.

B. Trend of Basal Area Growth

The maximum growth of basal area begins at the end of the sixth week of the growing season, or about June 10, as can be seen in Figures 12 and 13. This maximum growth continues until about the thirteenth week, or July 29. On some trees growth is completely stopped by the fifteenth week, or August 12, but other trees will continue to grow until the nineteenth week, or September 9. The end of radial growth at these dates came weeks before the leaves turned yellow and long before any critical temperatures occurred during the night. This did not happen until late October. This occurrence has been investigated by

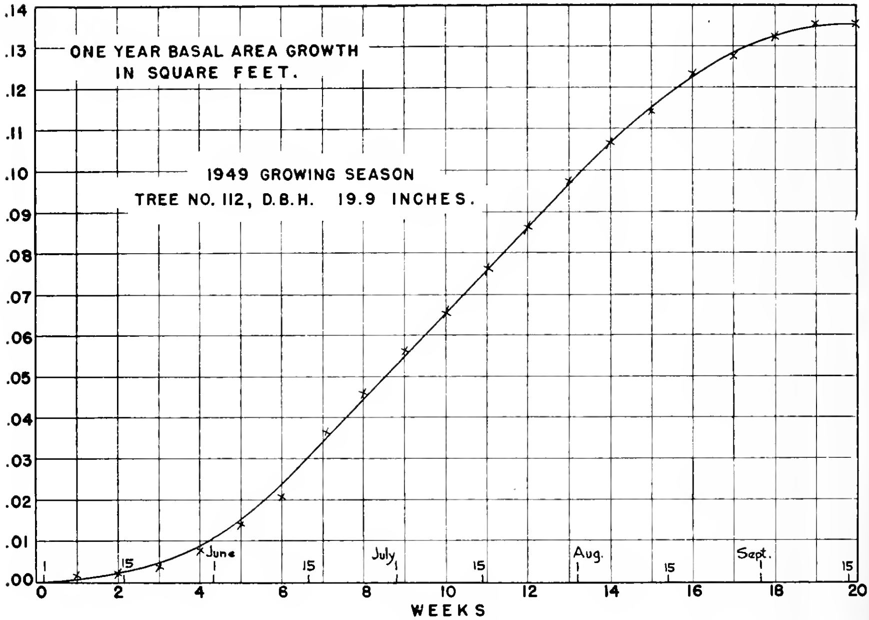

FIGURE 12. Basal area growth during 1949 season for Tree No. 112.

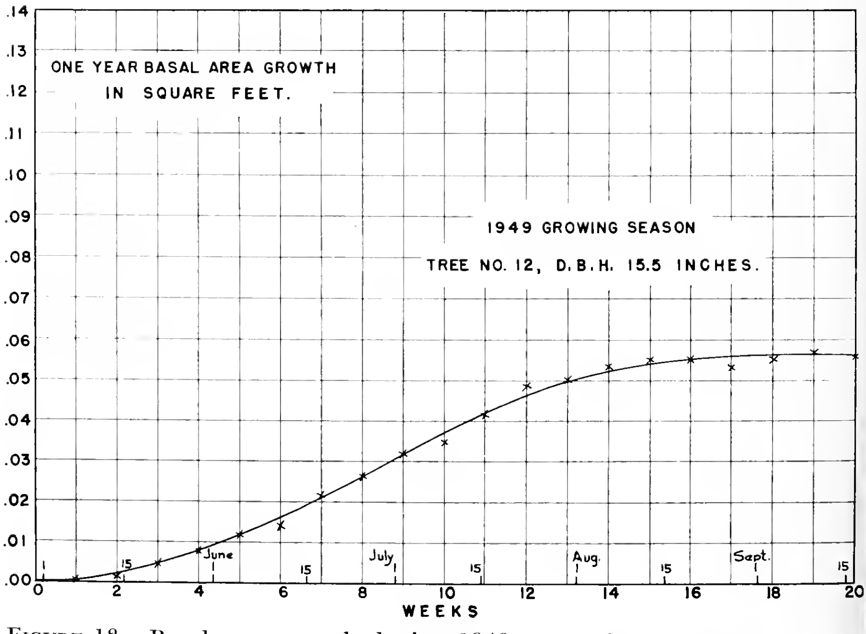

FIGURE 13. Basal area growth during 1949 season for Tree No. 12

Kramer (17). He finds that "for certain species the time at which dormancy begins and ends is closely related to the length of the day. The shortening days of late summer may bring about the cessation of growth in some of the more sensitive species considerably before it would be stopped by decreasing temperature." Kramer also points out that "among species investigated were yellowpoplar which would grow continuously in greenhouse if supplied continuous light. If no additional light was supplied, the growth would stop at the same time inside and outside greenhouse."

In order to investigate this further, the weekly basal area growth for all the sample trees was examined. There were 186 trees since seven trees were excluded from the experiment because they had been damaged when a new road was constructed. The trees were divided into three groups: (1) trees that were released during the winter between the two growing seasons investigated, (2) trees that were released during the last week in June, 1950, and (3) the control trees. Figure 14 shows the weekly growth of these three classifications. It is evident that the growth already falls off after the thirteenth week, or about July 29. A pronounced reduction in growth takes place on August 12, or at the end of the fifteenth week. This culmination of growth occurs in all

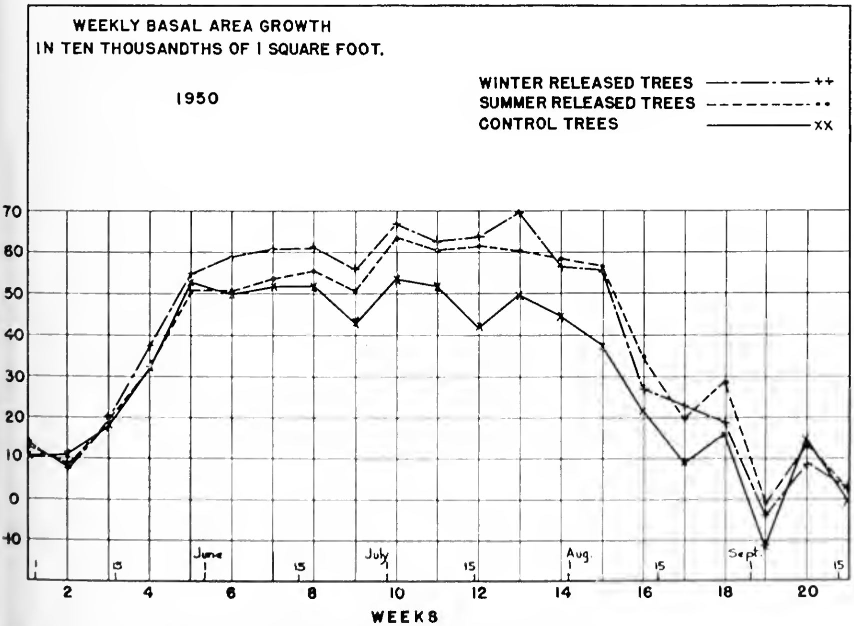

FIGURE 14. Weekly basal area growth of winter-released, summer-released, and control trees during 1950.

three groups of trees at about the same time, although the released trees, even in this period of declining basal area growth, will produce more growth.

C. Influence of Precipitation on Weekly Basal Area Growth

A comparison of the curve for basal area growth of 51 control trees during the 1950 growing season with the growth during 1949 (Figure 14), showed that the average value for each week's growth generally was higher during 1950. Since the 1950 growing season was wetter than the 1949 growing season, it was considered of interest to investigate how precipitation during each week of the growing season would influence the basal area growth. Figures 15 and 16 show the current average weekly growth of basal area of 51 control trees during the 1949 and 1950 growing seasons. These figures also show the weekly precipitations for the same period. Although the two curves show some similarity, the tendency seems to be that the effect of precipitation often does not register on the growth until the following week. The delay in reaction is particularly apparent when the heavy precipitation occurred a day or two before the micro-dendrometer measurements were taken. In such cases, the beneficial effect of the precipitation was carried over into the following week.

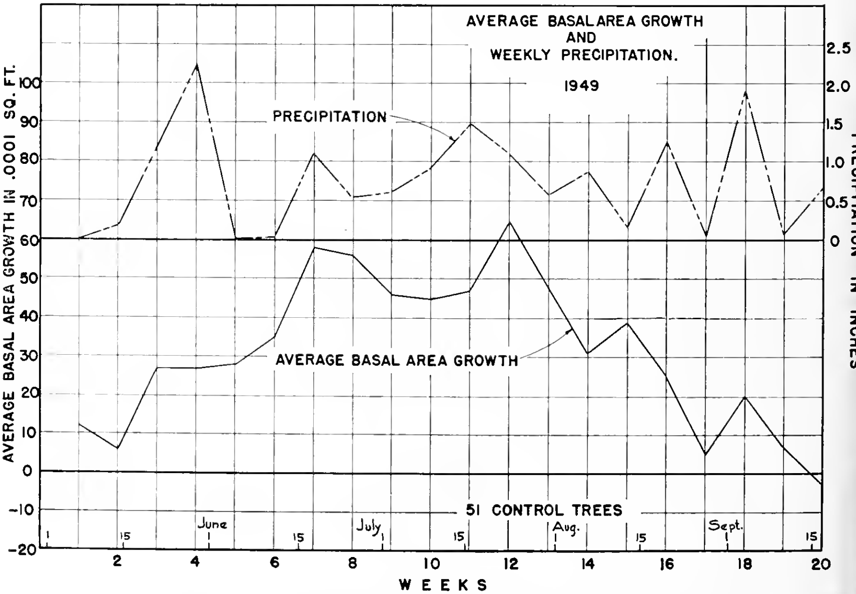

FIGURE 15. Current average weekly basal growth of 51 control trees related to weekly precipitation during 1949.

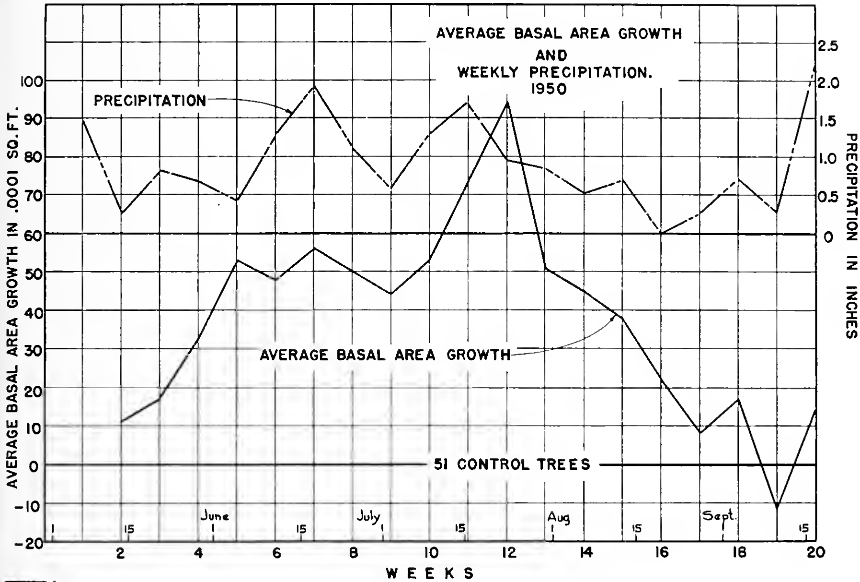

FIGURE 16. Current weekly basal area growth of 51 control trees related to weekly precipitation during 1950.

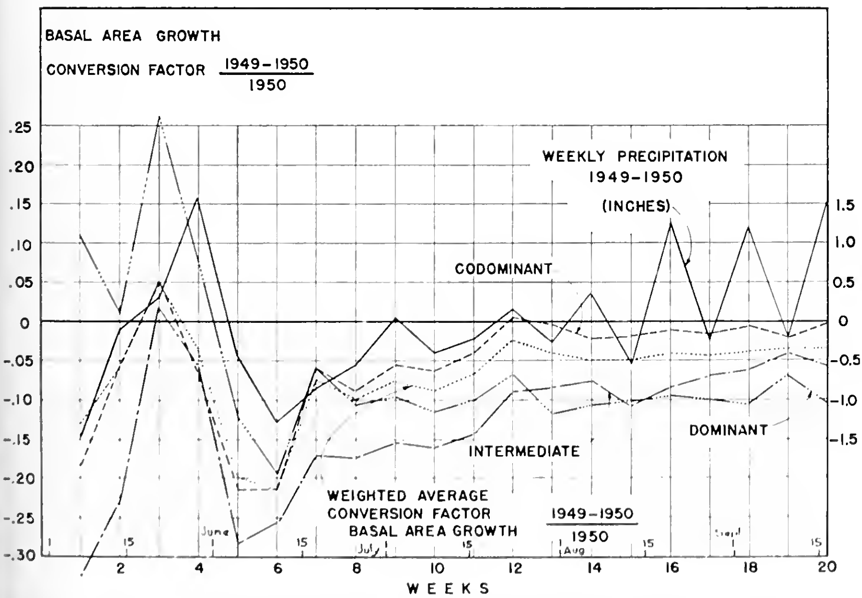

FIGURE 17. Relationship between conversion factor for basal area and differences in weekly precipitation between 1949 and 1950.

In order to investigate this further, the conversion factor for basal area growth between the two seasons has been plotted, along with the differences in weekly precipitation between 1949 and 1950. This is shown in Figure 17. The conversion factor for basal area growth is determined by the formula:

$$\frac{\text{Basal area growth for 1949} - \text{Basal area growth for 1950}}{\text{Basal area growth for 1950}} \qquad \text{(C)}$$

These curves show a great similarity up until the fourteenth week of the growing season. After this time the basal area convversion factor is almost constant, but there are great fluctuations in the difference between the weekly precipitation for the two years. Since the basal area growth has almost stopped after the fourteenth week of the growing season, the influence of precipitation on basal area growth is only minor. Applying statistical analysis of the trend of the curves for the first thirteen weeks of the growing season, indicates that the relationship between the two curves has a correlation coefficient of .784. This is highly significant.

Results and Discussion

A. Crown Release Classifications

As previously mentioned, 193 trees were used for measurements at the beginning of the experiment. Seven trees were damaged in the summer of 1949 as a result of road construction and were eliminated. The 186 remaining trees were divided into three main groups: 51 for control, 68 for release during the dormant season between 1949 and 1950, and 67 to be released during the growing season of 1950. The control trees were used for adjustment of variations between the two growing seasons. For this purpose the average growth of the control trees for each week during the 1949 growing season was compared with the corresponding average for the 1950 growing season, as shown in Figure 18. By means of the formula (C), previously shown, a correction factor for the growth of each week of the 1950 growing season was found.

From calculations it was found that it was not feasible to use the extent of the crown circumference that was released as a measure for crown release. Since some of the interference along the circumference might extend almost to the top of the crown of the sample tree, in other cases, it might be an interference on only the lower branches even if the amount of interference along the circumference was the same.

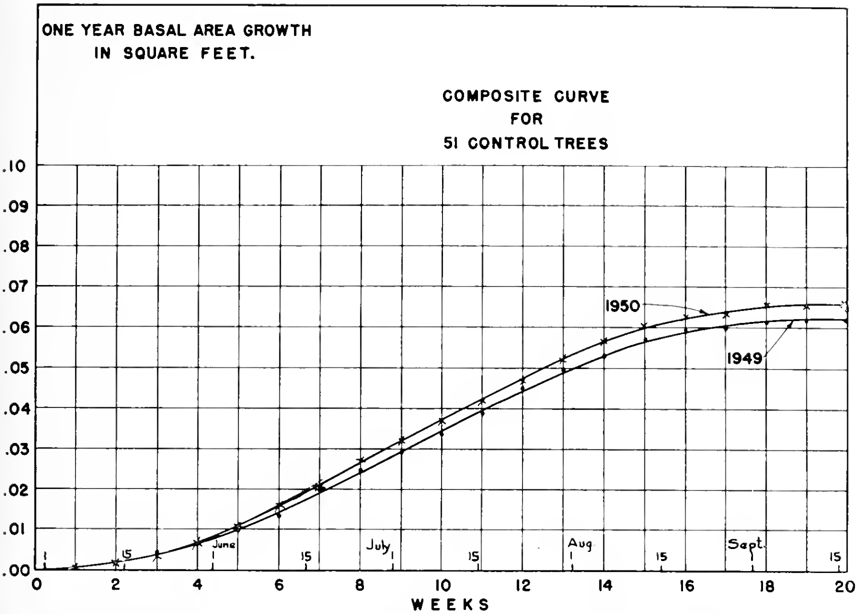

FIGURE 18. Weekly basal area growth of 51 control trees in 1949 and 1950.

Based on the formula for the crown surface and the amount of crown release the sample trees would get after some of the interference was removed, the sample trees were divided into several classes. The two main classes included the trees that received release during the dormant season between the 1949 and 1950 growing season, and the trees that were released during the latter part of June, 1950. Each of these main classes was divided into the percentage of crown surface that was released. The classifications used were: (1) less than 12.5 per cent, (2) 12.5 to 37.4 per cent, (3) 37.5 to 62.4 per cent, and (4) 62.5 to 87.4 per cent. The average basal area growth for each week was found for these classifications for both 1949 and 1950. By means of the correction factors determined by formula (C) the 1950 figures were adjusted for weekly variations in growth between the two growing seasons using the following formula: (D)

(1950 reading) — (conversion factor x 1950 reading) = Adjusted reading

B. Crown Release During the Dormant Season

In order to compare the corrected 1950 growth with the 1949 growth on basal area, this relationship is shown for the different classes of percentage crown releases in Figures 19 to 22. A comparison of

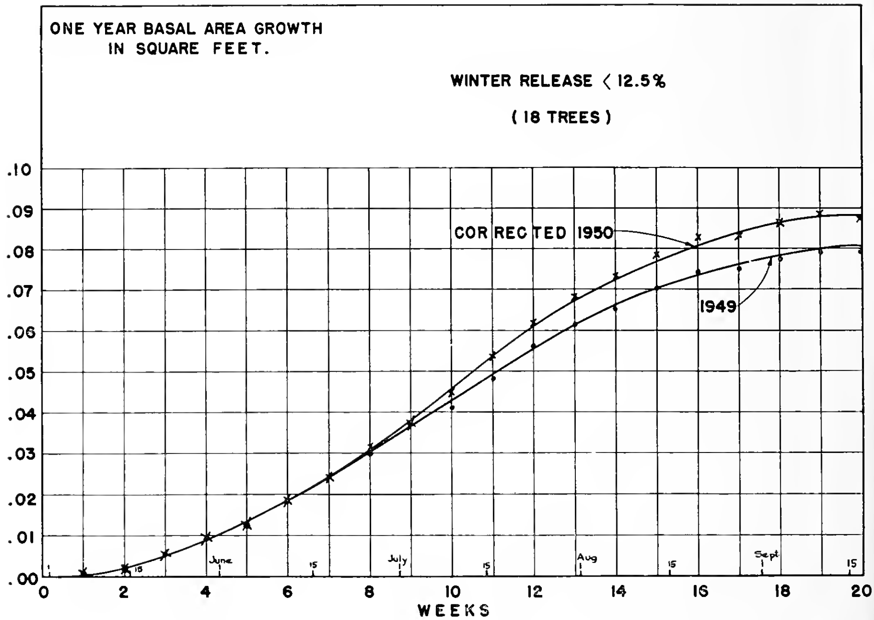

FIGURE 19. Weekly accumulative basal area growth in 1949 and 1950 of 18 trees given winter release of less than 12.5 per cent.

Figures 19 to 22 with each other, shows that the larger the percentage crown release during the dormant season, the larger the percentage growth difference of basal area at the end of the growing season. Figure 19 shows that the average basal area growth for trees that received less than 12.5 per cent crown release during the dormant season between 1949 and 1950 have had an increase in growth during 1950 of about 11.4 per cent. The trees that received a crown release of from 62.5 to 87.4 per cent grew 54.0 per cent more on the basal area during 1950. Although the faster growth was not noticeable until the eighth week of the 1950 growing season on the trees that received less than 12.5 per cent crown release, the increased growth started gradually earlier on the trees what were released more. On the trees that received releases ranging from 62.5 to 87.4 per cent, the increased growth was already measurable during the third week of the growing season, or about the last week in May.

C. Crown Release During the Growing Season

As can be seen in Figures 23 to 26, the trees that were released during the latter part of June did not show as great an over-all increase on the basal area growth as the trees released during the dormant

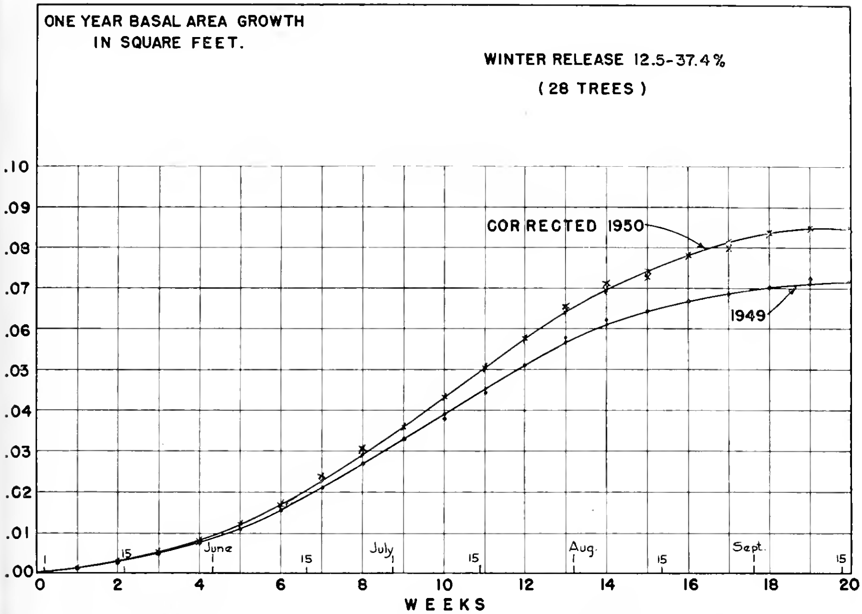

FIGURE 20. Weekly accumulative basal area growth in 1949 and 1950 of 28 trees given winter release of 12.5-37.4 per cent.

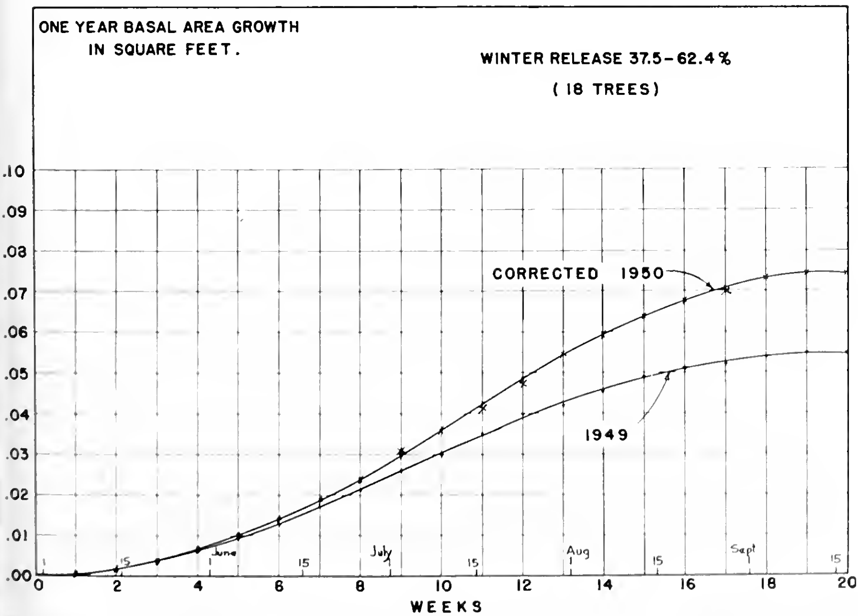

FIGURE 21. Weekly accumulative basal area growth in 1949 and 1950 of 18 trees given winter release of 37.5-62.4 per cent.

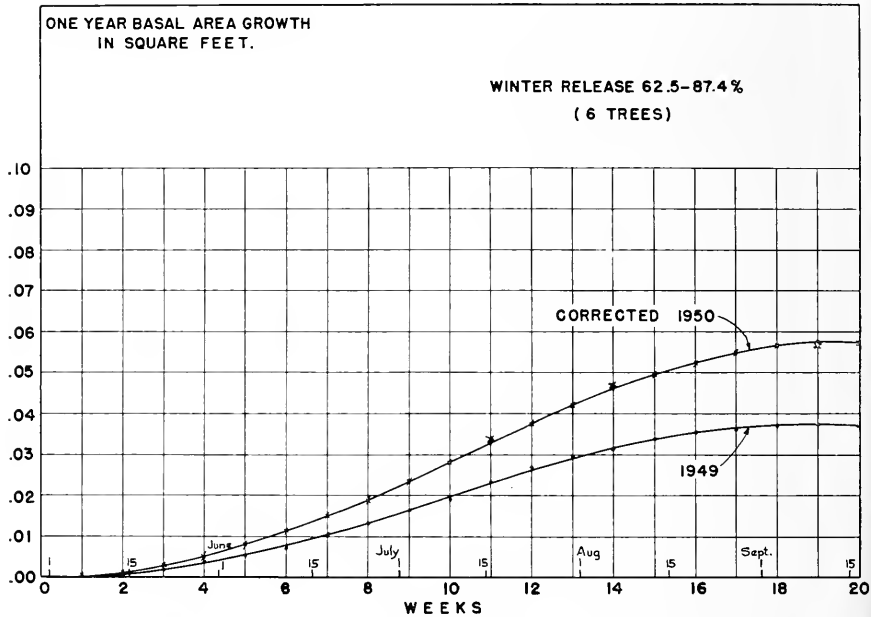

FIGURE 22. Weekly accumulative basal area growth in 1949 and 1950 of 6 trees given winter release of 62.5-87.4 per cent.

season, since the former had only part of the 1950 growing season under released condition. The increase in basal area growth during 1950 for the trees that received less than 12.5 per cent release during the summer was 9.7 per cent. The trees that had crowns released between 62.5 and 87.4 per cent, increased 26.0 per cent in basal area growth. It is interesting to note that even though most of the leaves were out on the trees before they were released, and although these leaves already had completed their cell structure, the trees that received the most crown release increased the most in basal area growth compared to the 1949 growing season. This agrees with the findings of Heinicke and Childers (12). They showed that the rate of photosynthesis for an entire apple tree increased progressively with increase in light intensity. These investigators also showed that many of the interior leaves received 1 per cent or less of the light received by the peripheral leaves. Therefore, even in full sunlight many of the leaves on a tree do not photosynthesize at their maximum capacity. Hence the greater the intensity of the incident light, the greater average rate of photosynthesis per unit of leaf area. Meyer and Anderson (19) state that "total photosynthesis per tree increases with increased illumination up to the maximum possible sunlight intensity." Møller (22) states that "the constant factor as far as the number of leaves per hectare is

concerned, may be explained in this way that the light necessary for the CO_2 assimilation is rather close to the minimum compared to the other growth factors."

In line with the foregoing findings, the increased growth of the trees that were released during the growing season may be explained in this way: before release many of the leaves were assimilating below their capacity. After the release they received higher light intensity. This brought the assimilation of these leaves closer to their maximum production. During the years following release, the basal area growth will be further increased, as will be shown later from a stem analysis of tree No. 101. This further increase may be attributed to the enlargement of the crown, which causes the crown surface to increase. The relation between crown surface and basal area growth has already been established, as shown in Figure 11.

The release of the sample trees took place during the latter part of June and was finished before the measurements were taken for the growth of the eighth week. In Figures 23 to 26 it will be noted that already on the measurements for the eighth week an increased growth reaction has taken place. This increased growth continued to the end of the growing season. At that time the trees that were released the most showed the greatest percentage increase over their 1949 growth.

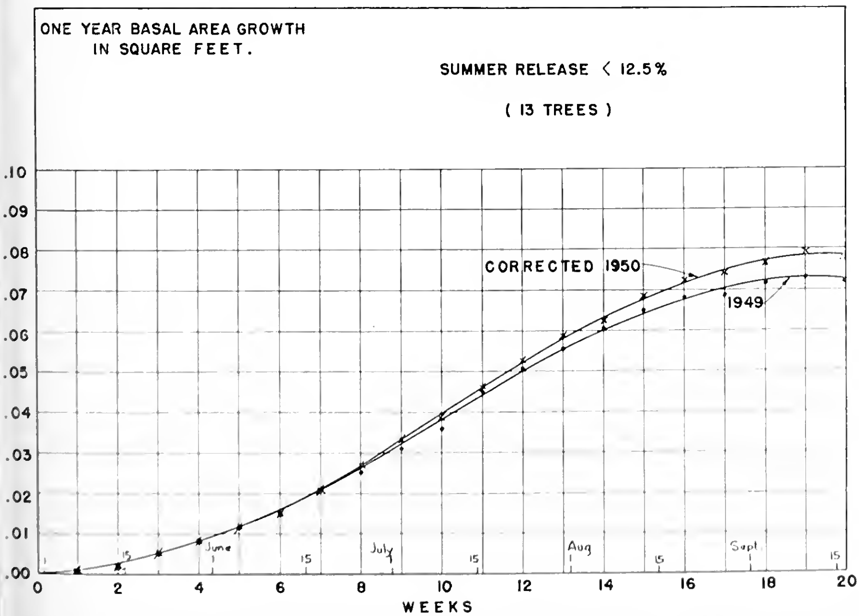

FIGURE 23. Weekly accumulative basal area growth in 1949 and 1950 of 13 trees given summer release of less than 12.5 per cent.

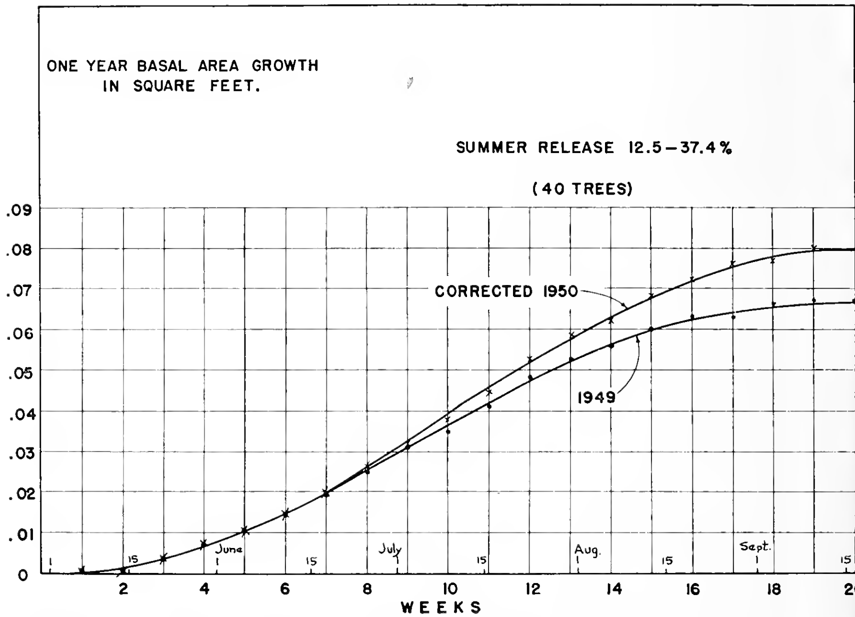

FIGURE 24. Weekly accumulative basal area growth in 1949 and 1950 of 40 trees given summer release of 12.5-37.4 per cent.

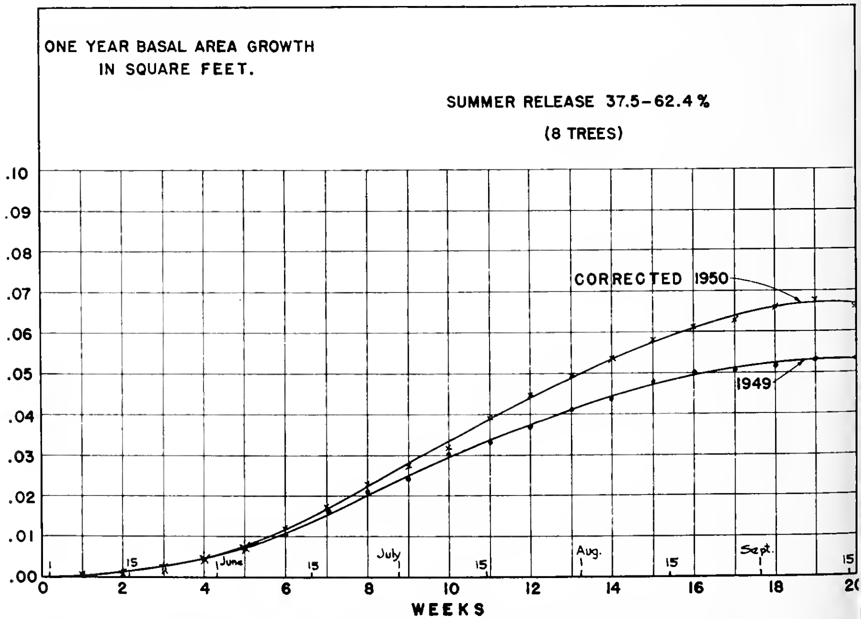

FIGURE 25. Weekly accumulative basal area growth in 1949 and 1950 of 8 trees given summer release of 37.5-62.4 per cent.

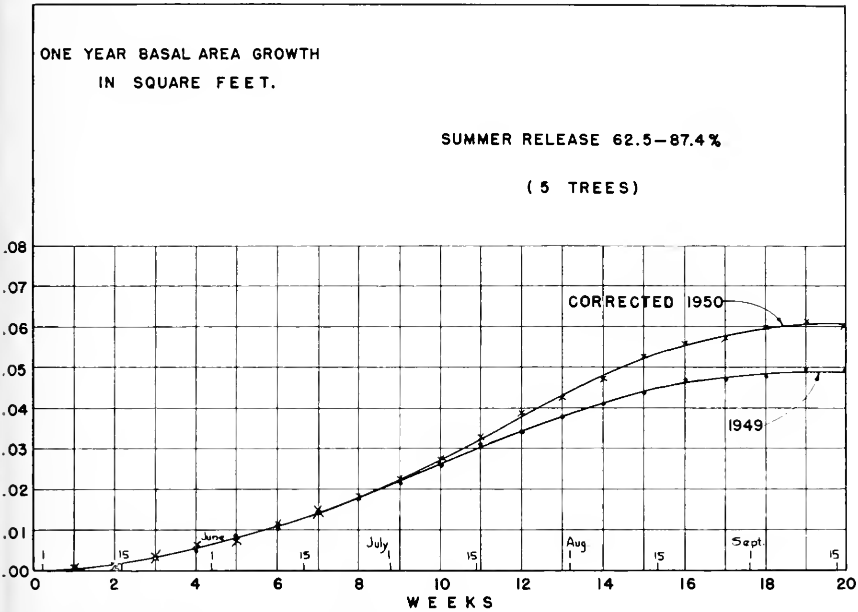

FIGURE 26. Weekly accumulative basal area growth in 1949 and 1950 of 5 trees given summer release of 62.5-87.4 per cent.

This immediate response to release checks very well with the findings of Stephens and Spurr (26) who, in red pine, found that the increased growth rate could be noted within twenty-four hours after release.

These results show that for various degrees of release there is a corresponding increased rate of basal growth increasing with the amount of crown surface released. Consequently, it has not been possible to determine any stagnation or decrease in growth rate due to a shock reaction caused by a sudden release of the sample trees used in this experiment.

D. REACTION TO CROWN RELEASE DURING DORMANT SEASON OF TREES OF DIFFERENT CROWN CLASSES

In order to further investigate the reaction on the individual trees of various degrees of crown release during both the dormant season and the growing season, the trees were divided into crown classes. The three main groups were control trees, winter-released trees, and summer-released trees. They were all divided into dominant, codominant, and intermediate trees. By comparing the growth of dominant control trees for 1950 with the growth for 1949, and using formula (C) on

page 28, the correction factors for the different weeks of the growing season were found. These correction factors were applied to the weekly 1950 growth for the dominant trees that were released during the dormant season and for those released during the growing season of 1950. The same procedure was used for codominant and intermediate trees.

In Figures 27, 28, and 29, the corrected 1950 growth is shown with the growth for 1949 for dominant trees that respectively have received a winter release of less than 12.5 per cent, 12.5 to 37.4 per cent, and 37.5 to 62.4 percent. From these curves it is evident that the more the dominant trees are released during the dormant season, the more they grow on the basal area during the following growing season. The difference for dominant trees between the corrected weekly growth figures for 1950 and 1949 weekly growth was placed over the 1949 growth and the percentage growth increase was found. This relationship is shown in Figure 30, which indicates that by the end of the growing season the trees which had less than 12.5 per cent of their crown released, grew 8.5 per cent more than they did in 1949. The trees that received a crown percentage release of between 12.5 and 37.4 per cent, increased 12.5 per cent, whereas the trees that were released between 37.5 and 62.4 per cent, increased 46.0 per cent. Although

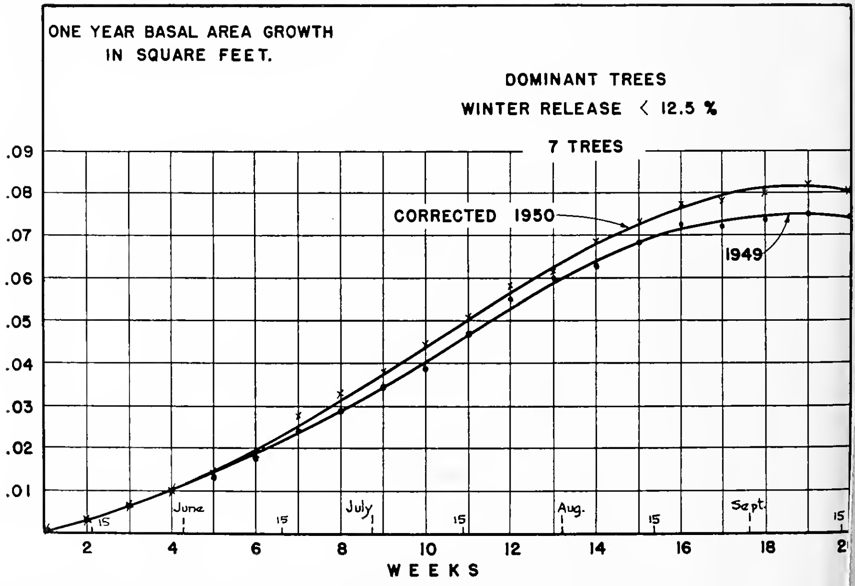

FIGURE 27. Weekly accumulative basal area growth in 1949 and 195 of 7 dominant trees given winter release of less than 12.5 per cent.

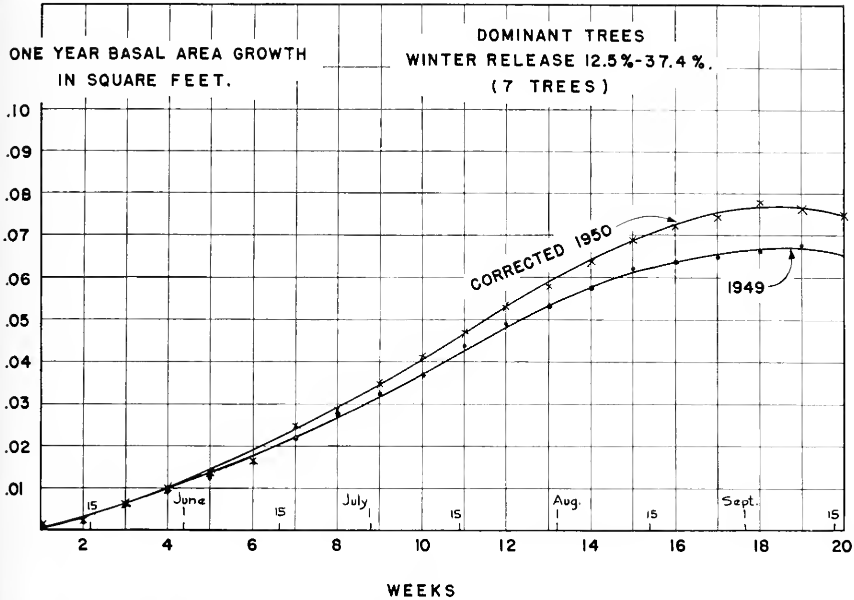

FIGURE 28. Weekly accumulative basal area growth in 1949 and 1950 of 7 dominant trees given winter release of 12.5-37.4 per cent.

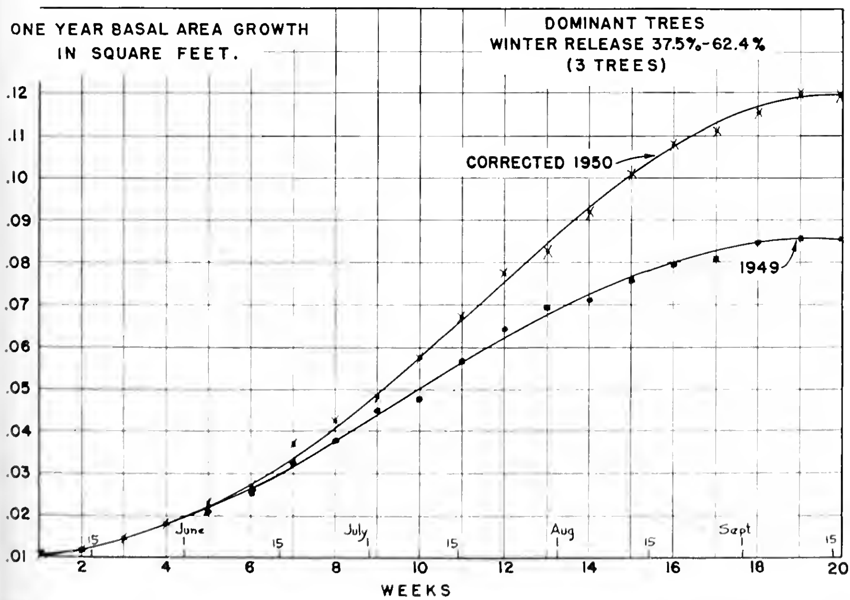

FIGURE 29. Weekly accumulative basal area growth in 1949 and 1950 of 3 dominant trees given winter release of 37.5-62.4 per cent.

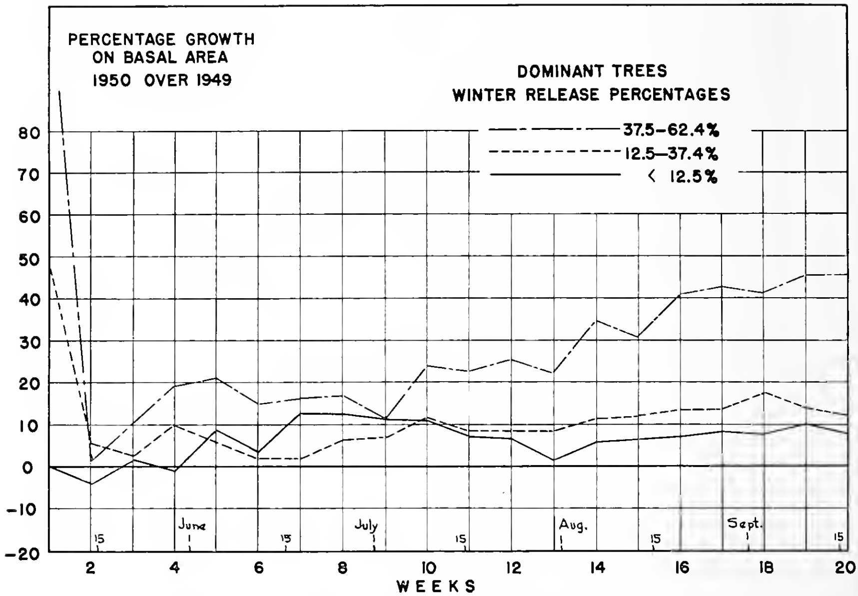

FIGURE 30. Percentage weekly basal area growth in 1949 and 1950 of dominant trees given different percentages of winter release.

these figures cannot be deemed conclusive because only relatively few trees fell in this category, they are indicative of the effect that will take place after different percentages of release of crown surfaces of dominant trees have been made.

Figures 31, 32, 33, and 34 show the growth of codominant trees that received different amounts of crown release during the dormant season. The release classifications that are represented in these figures are crown releases less than 12.5 per cent, between 12.5 and 37.4 per cent, and between 37.5 and 62.4 per cent. As in former figures, the 1950 growth is corrected based on the differences in growth of codominant control trees during the 1949 and 1950 growing season. The results may be considered rather indicative, since all the classifications are represented by a fair number of trees. As will be noticed from the figures, there is no difference between the growth of 1949 and 1950 until the sixth week. After that there is a steadily increasing difference between the two growing seasons corresponding with the amount of release the crowns have received. Figure 42 shows the difference between the basal area growth during the two seasons expressed as a percentage over 1949 growth. As will be noted, there are great percentage variations during the first five weeks. This is understandable,

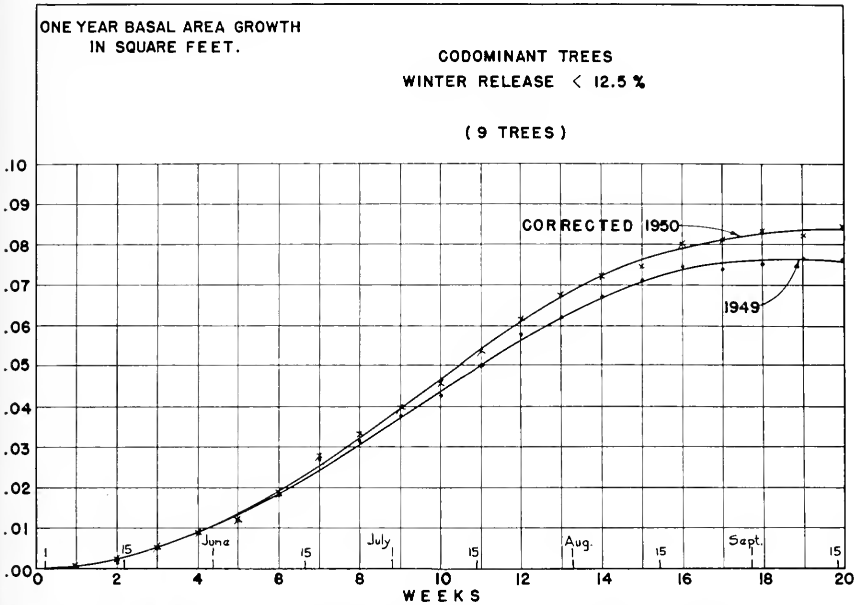

Figure 31. Weekly accumulative basal area growth in 1949 and 1950 of 9 codominant trees given winter release of less than 12.5 per cent.

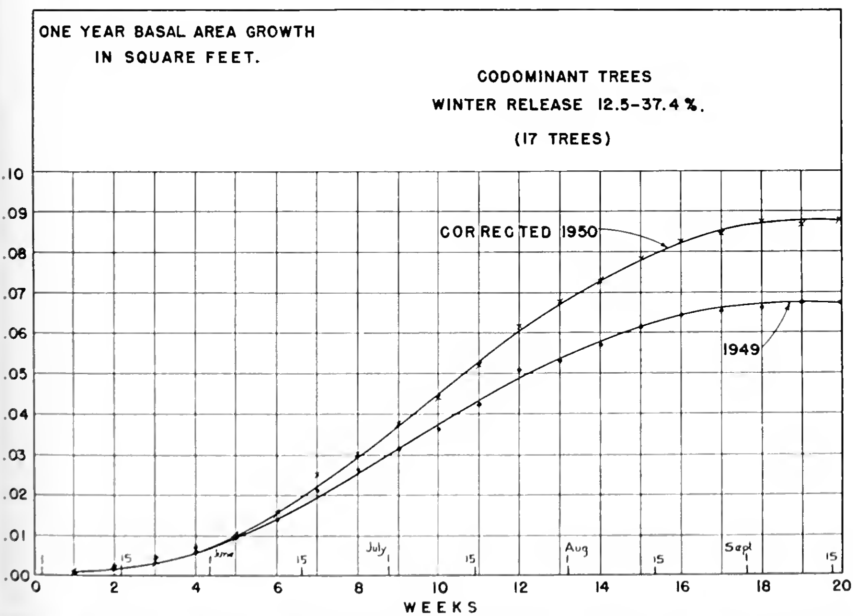

Figure 32. Weekly accumulative basal area growth in 1949 and 1950 of 17 codominant trees given winter release of 12.5-37.4 per cent.

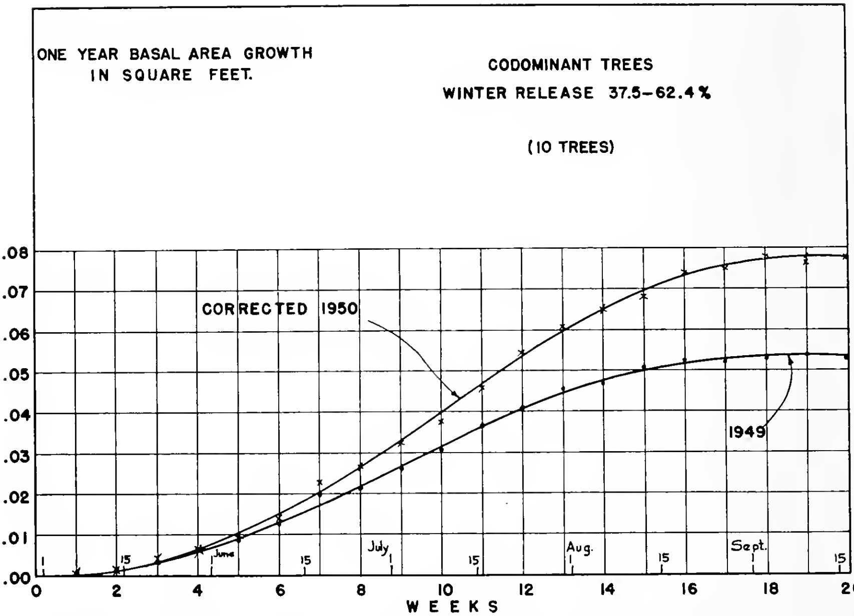

FIGURE 33. Weekly accumulative basal area growth in 1949 and 1950 of 10 codominant trees given winter release of 37.5-62.4 per cent.

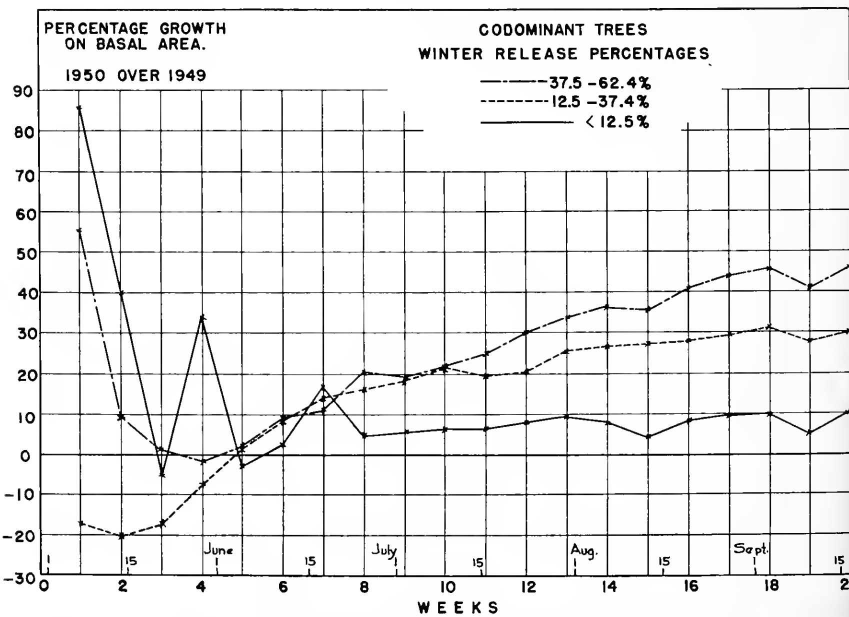

FIGURE 34. Percentage weekly basal area growth in 1949 and 1950 of codominant trees given different percentages of winter release.

since small variations at that stage will represent large percentage differences. Therefore, not until the growing season gets underway, or at about the fifth or sixth week, will the curves be indicative of the differences in growth of the three classifications of release. It will be noted that codominant trees that receive the most crown release will grow the most in basal area during the growing season following the release.

Figures 35, 36 and 37 represent the growth of intermediate trees that have received different percentages of crown releases during the dormant season. The corrected 1950 growth was obtained by means of corrected factors from the 1949 and 1950 growth of intermediate control trees. Figure 35, representing intermediate trees having received crown releases between 37.5 and 62.4 per cent, shows no difference in growth between the corrected 1950 data and the growth for 1949 until about the ninth week of the growing season. Figure 36, however, representing intermediate trees having received crown releases between 62.5 and 87.4 per cent, shows a difference in growth during the two growing seasons on the third week of the growing season. Since these two classifications are only represented by 2 and 4 trees respectively, these findings cannot be deemed conclusive. Figure 37 shows the percentage difference in growth on basal area based on corrected 1950

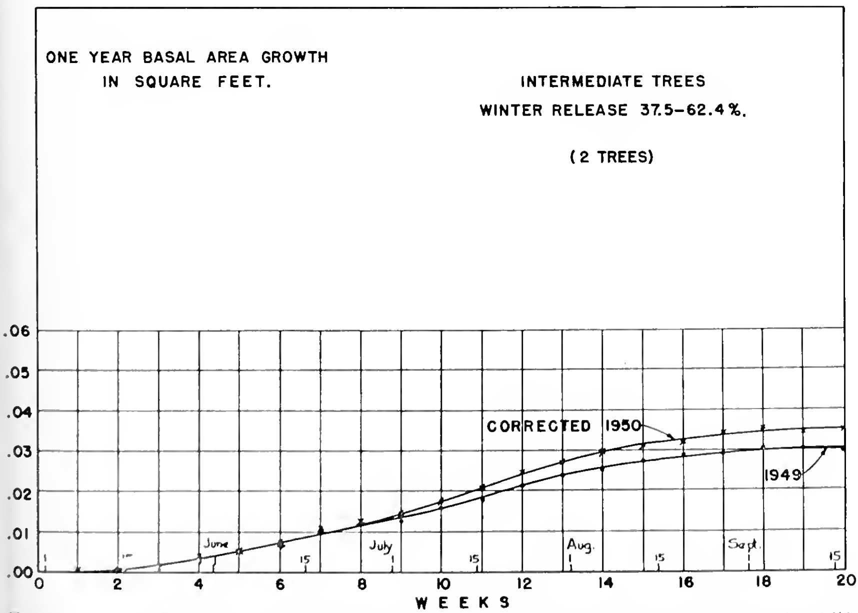

FIGURE 35. Weekly accumulative basal area growth in 1949 and 1950 of 2 intermediate trees given winter release of 37.5-62.4 per cent.

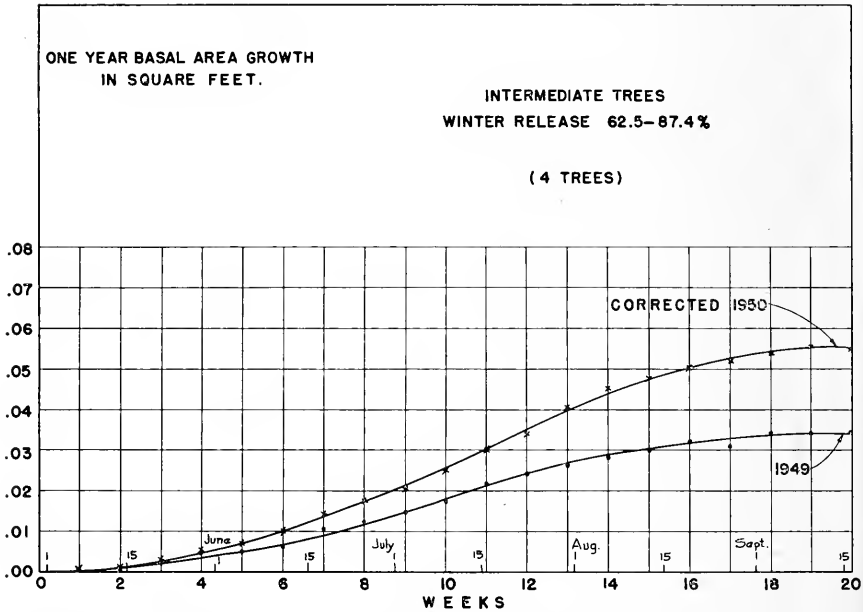

FIGURE 36. Weekly accumulative basal area growth in 1949 and 1950 of 4 intermediate trees given winter release of 62.5-87.4 per cent.

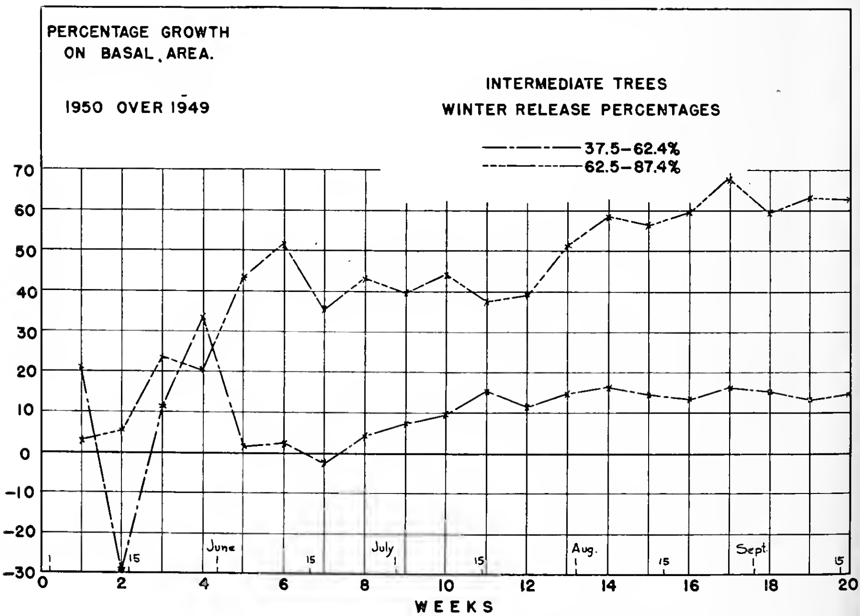

FIGURE 37. Percentage weekly basal area growth in 1949 and 1950 of intermediate trees given different percentages of winter release.

measurements over 1949. The pattern here also is irregular until the seventh week, after which the trend in growth shows a remarkable difference. Because of the few sample trees in these classifications, the results cannot be termed significant. The trend of the curves, however, shows that the greater the percentage of crown release received by the intermediate trees, the greater the increase in basal area growth during the growing season after release.

E. Reaction to Crown Release During Growing Season of Trees of Different Crown Classes

The following sets of curves represent the different crown classifications and their reaction on basal area growth to various percentages of crown releases during the growing season. Figures 38 and 39, which show the average data of all the sample trees, indicate the amount of increase on basal area growth on winter-released and summer-released trees. These figures illustrate that the summer-released trees grew proportionally less than the trees that were released during the dormant season. The reason for this probably is that only part of the growing season remained after the release took place.

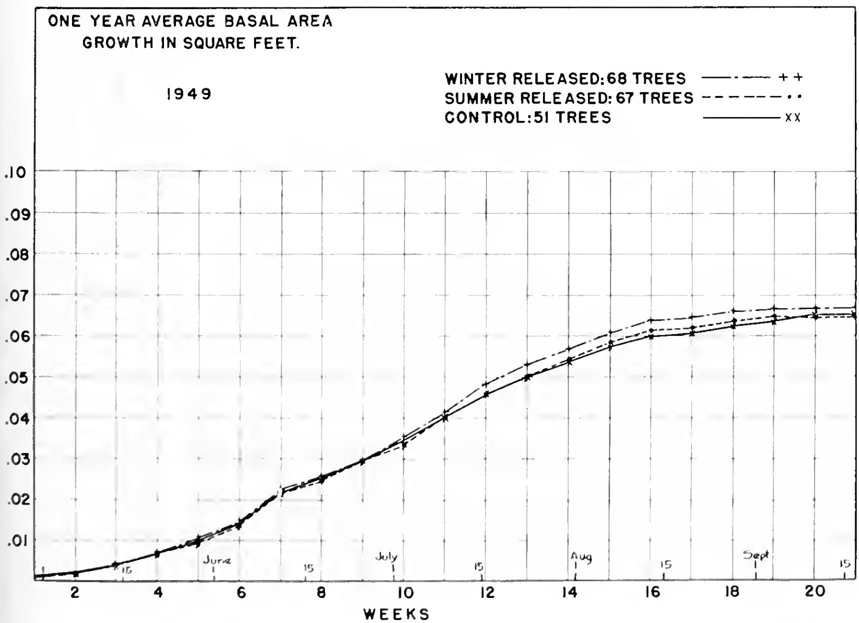

Figure 38. Weekly accumulative basal area growth in 1949 of winter-released, summer-released, and control trees.

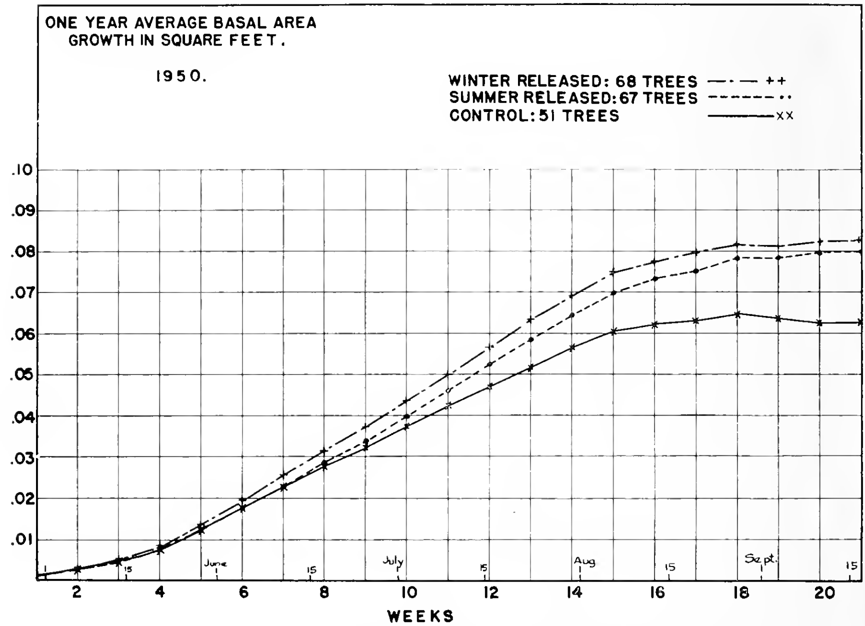

FIGURE 39. Weekly accumulative basal area growth in 1950 of winter-released, summer-released, and control trees.

Figures 40, 41, and 42 show the reaction on basal area growth of dominant trees to crown releases of less than 12.5 per cent and between 12.5 and 37.4 per cent. Although the release took place during the seventh and eighth weeks of the growing season, no growth difference is noticeable on the dominant trees until the end of the fourteenth week for the trees that received the greater amount of release. On the dominant trees that received less than a 12.5 per cent crown release, the increased growth during the 1950 growing season does not show up until the end of the sixteenth week. This delay in reaction also is apparent in Figure 42, which shows that the percentage growth on basal area based on corrected 1950 growth over 1949 growth, runs along the zero line until the fourteenth and sixteenth weeks for the two classifications of crown release. By the end of the growing season, however, it shows that the dominant trees that have received the greatest percentage release of the crowns during the summer have the greatest percentage increase in basal area growth.

Figures 43, 44, 45, 46, and 47 show the reaction of codominant trees to various degrees of crown release during the growing season. It is interesting to note in Figure 43 that although the release of the crown took place during the seventh and eighth weeks of the growing

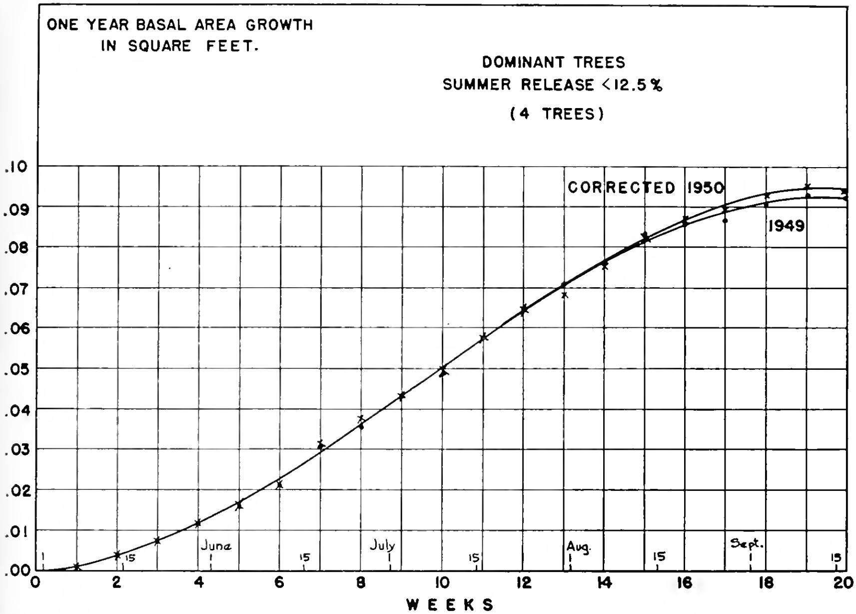

FIGURE 40. Weekly accumulative basal area growth in 1949 and 1950 of 4 dominant trees given winter release of less than 12.5 per cent.

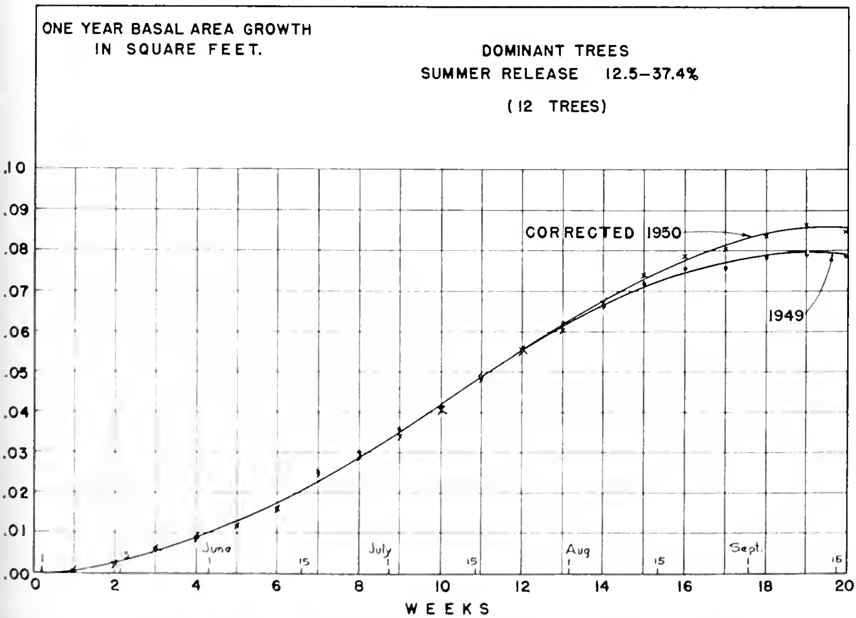

FIGURE 41. Weekly accumulative basal area growth in 1949 and 1950 of 12 dominant trees given winter release of 12.5-37.4 per cent.

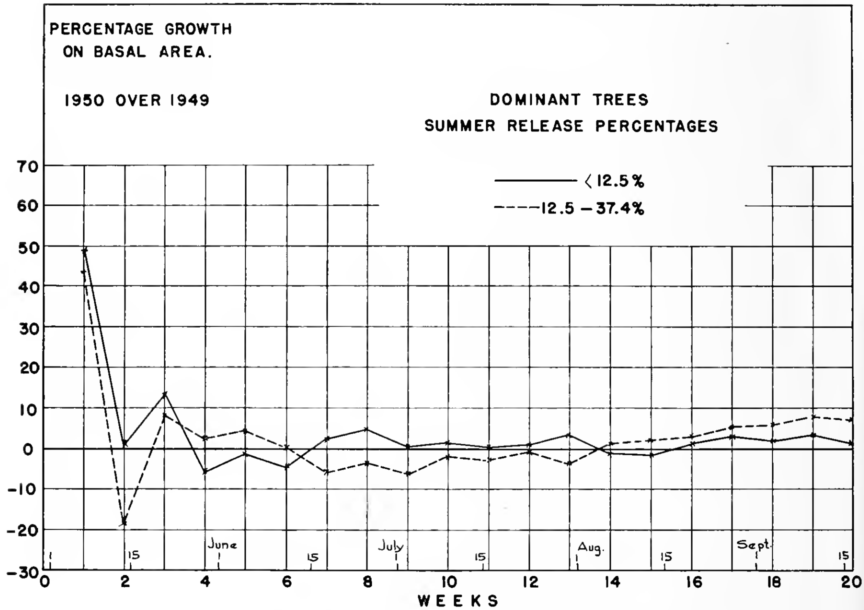

FIGURE 42. Percentage weekly basal area growth in 1949 and 1950 of dominant trees given different percentages of summer release.

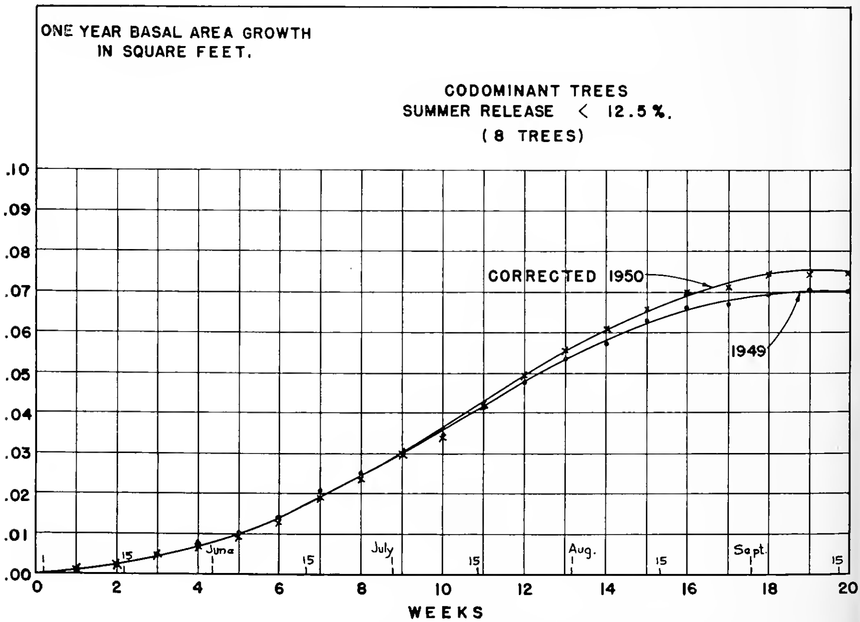

FIGURE 43. Weekly accumulative basal area growth in 1949 and 1950 of 8 codominant trees given summer release of less than 12.5 per cent.

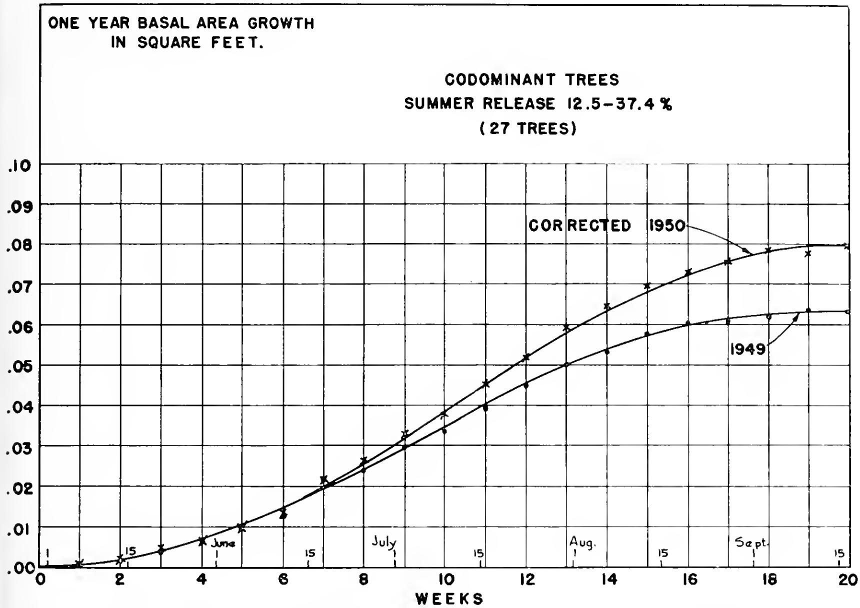

FIGURE 44. Weekly accumulative basal area growth in 1949 and 1950 of 27 codominant trees given summer release of 12.5-37.4 per cent.

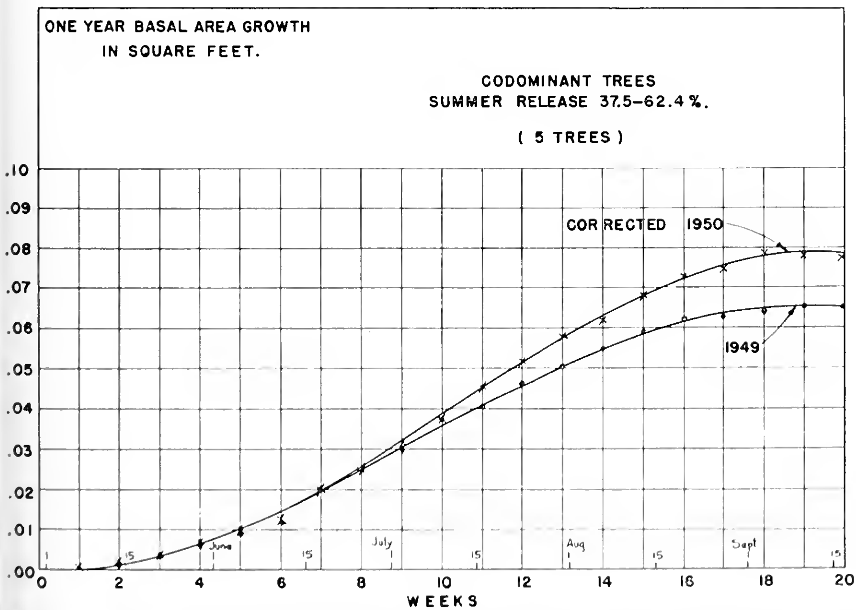

FIGURE 45. Weekly accumulative basal area growth in 1949 and 1950 of 5 codominant trees given summer release of 37.5-62.4 per cent.

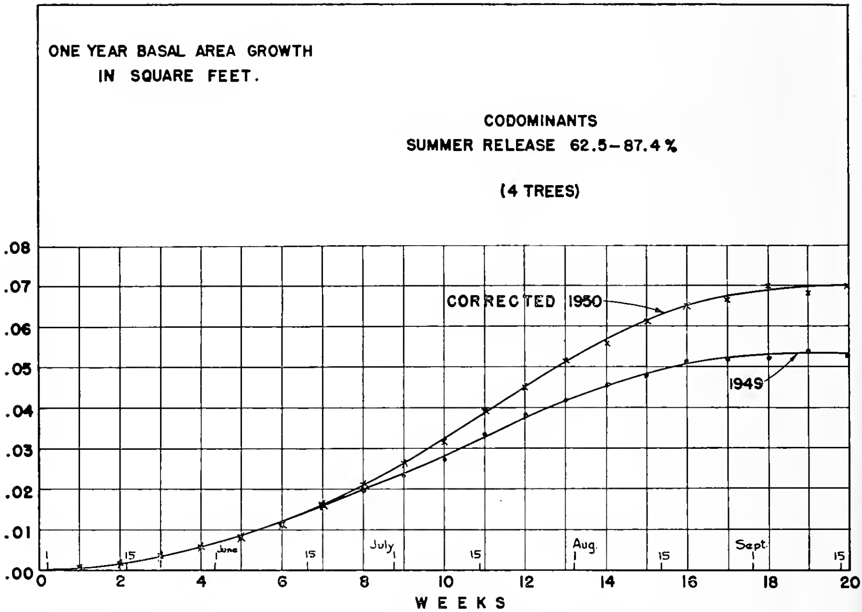

FIGURE 46. Weekly accumulative basal area growth in 1949 and 1950 of 4 codominant trees given summer release of 62.5-87.4 per cent.

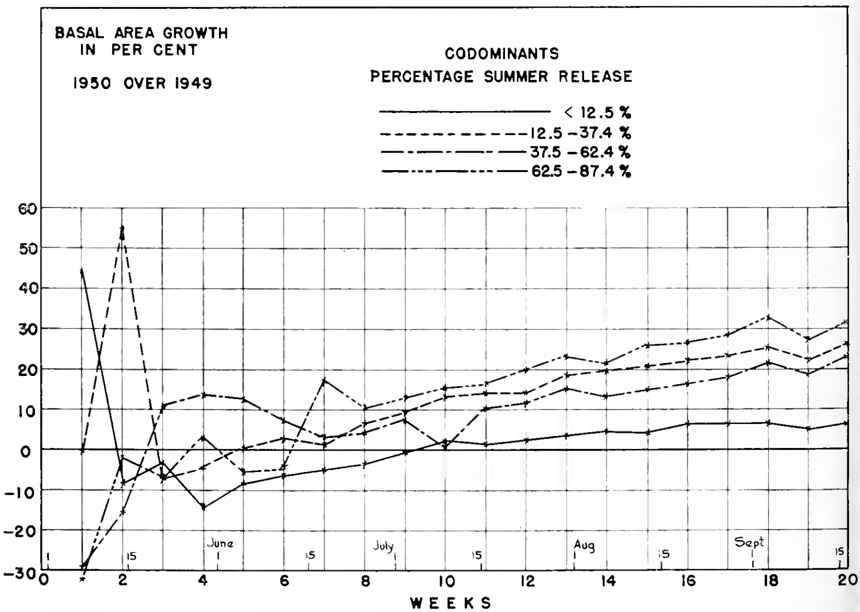

FIGURE 47. Percentage weekly basal area growth in 1949 and 1950 of codominant trees given different percentages of summer release.

season, there is no increased growth during 1950 until the tenth week on the trees that received a release of less than 12.5 per cent. For the other groups that received greater percentage releases of their crowns, the reaction is already noticeable on the measurements during the eighth week, only a few days after the release took place. Although the differences for the different percentages of release are considerable, the corrected 1950 growth on the basal area is much less compared to the winter-released codominant trees. Figure 47 shows the percentage growth on basal area—corrected 1950 growth over 1949 growth. The irregularities also are apparent here until about the eighth week, after which the curves show steady trends. It is apparent, however, that the percentage increase does not correspond to the percentage of crown release. This may be explained by the lack of representation in the crown release classes of 37.5 to 62.4 per cent, and 62.5 to 87.4 per cent, which contain only 5 and 4 trees, respectively.

Figures 48, 49, 50, and 51 show the difference in growth between corrected 1950 and 1949 growth for intermediate trees that had their crowns released during the growing season. Figures 48, 49, and 50 represent, respectively, releases from 12.5 to 37.4 per cent, 37.5 to 62.4 per cent, and more than 87.5 per cent crown releases. Although there are only 2 trees in each of these groups, the figures have been included in the discussion because they do give an indication of the reaction of intermediate trees to crown releases during the growing season. As can be seen in Figures 48 and 49, the corrected 1950 growth showed greater values during the third week of the growing season as compared to the 1949 growth. Although no definite explanation can be given, it is possible that since these trees were growing under starvation conditions in regard to light and perhaps root competition, cutting of some trees to give other trees crown release during the dormant season may have affected the trees in question. Such cuttings may have affected root competition of the summer-released intermediate trees without affecting the light density of the crowns.

As can be seen in Figures 48, 49, and 50, the great difference in basal area growth between the two growing seasons did not occur until after the eighth week. It is believed that the increased growth rate of the intermediate trees after some of the neighboring trees have been cut is partly due to release from root competition, and partly to the increased amount of light that reaches the crown. This problem will be discussed later on page 64.

Figure 51 shows the percentage growth of basal area based on corrected 1950 data over 1949 growth. After the usual irregularities until about the eighth week, the different degrees of release show a

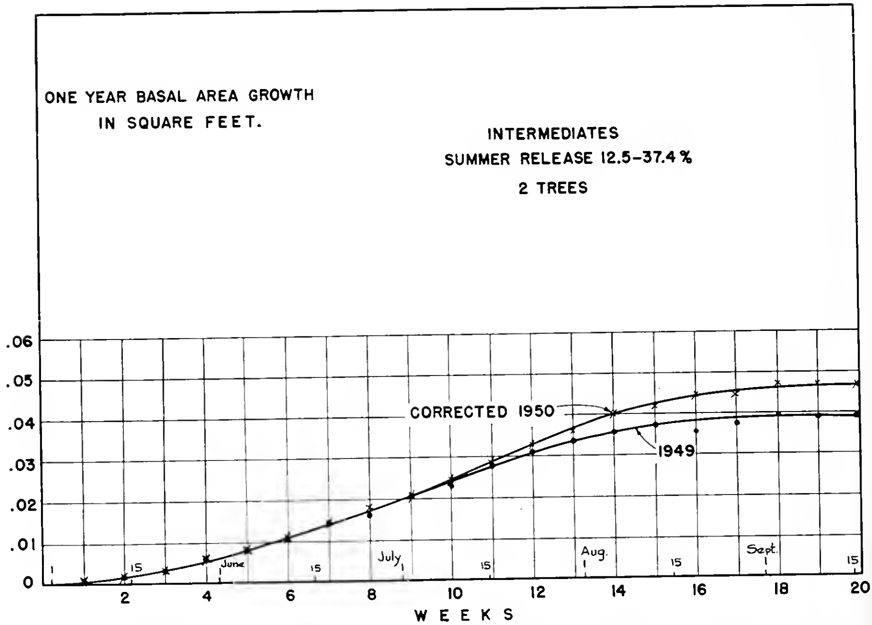

Figure 48. Weekly accumulative basal area growth in 1949 and 1950 of 2 intermediate trees given summer release of 12.5-37.4 per cent.

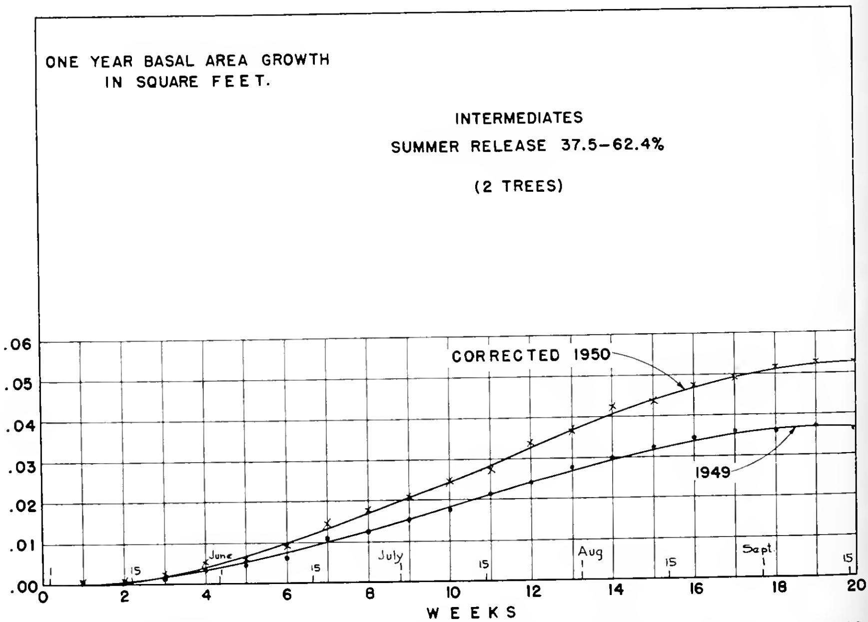

Figure 49. Weekly accumulative basal area growth in 1949 and 1950 of 2 intermediate trees given summer release of 37.5-62.4 per cent.

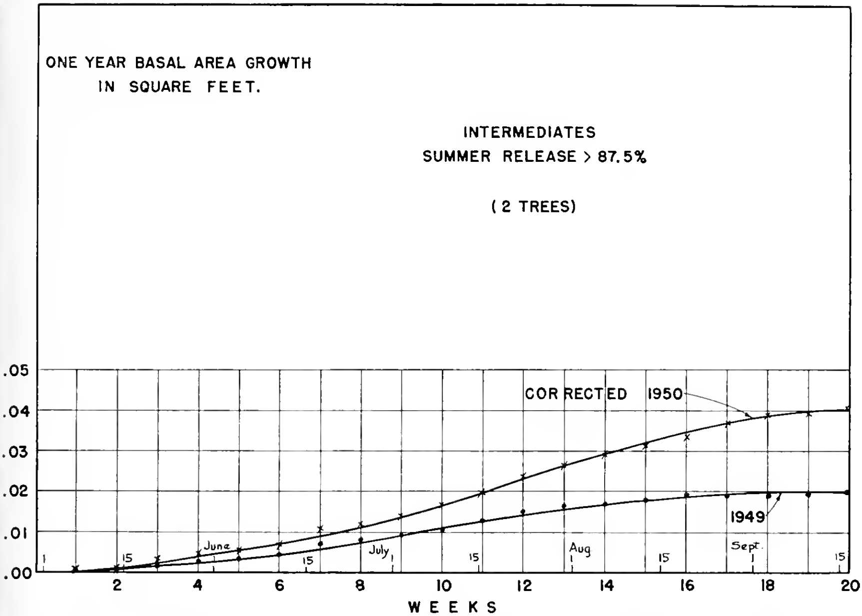

FIGURE 50. Weekly accumulative area growth in 1949 and 1950 of 2 intermediate trees given summer release of more than 87.5 per cent.

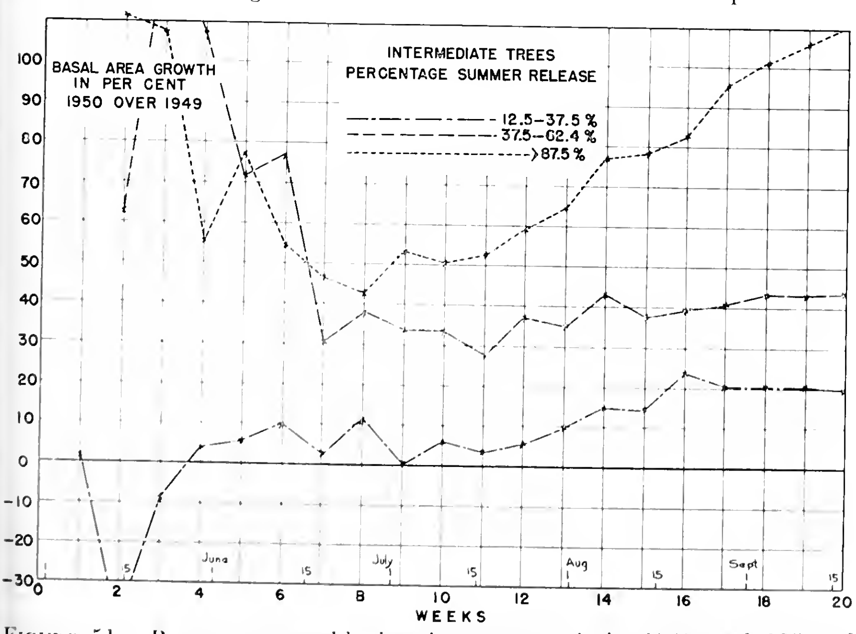

FIGURE 51. Percentage weekly basal area growth in 1949 and 1950 of intermediate trees given different percentages of summer release.

growth corresponding to the amount of release the trees have received. The increased growth of these trees is remarkable, since most of their crowns were worn down to a considerable extent. In spite of this, these trees responded extremely well to the release they received. Although a sudden and complete release of worn down intermediate trees cannot be recommended because it often will cause wind breakage, the trees will react favorably to severe releases if no damage occurs to them from other causes.

F. Reaction of Different Crown Classes to the Same Percentage of Crown Release

In order to investigate the relative reaction of various crown classes to the same percentage of winter release, Figures 52, 53, 54, and 55 were constructed. The general trend in these figures seems to be that for the same percentage release, the lower crown class reacts by growing correspondingly more during the 1950 growing season than does the higher crown class. The only exception is for the release that was less than 12.5 per cent. Here there does not seem to be any difference between the growth increase of dominant and codominant trees. The reason for this may be that the reaction from a small amount of release,

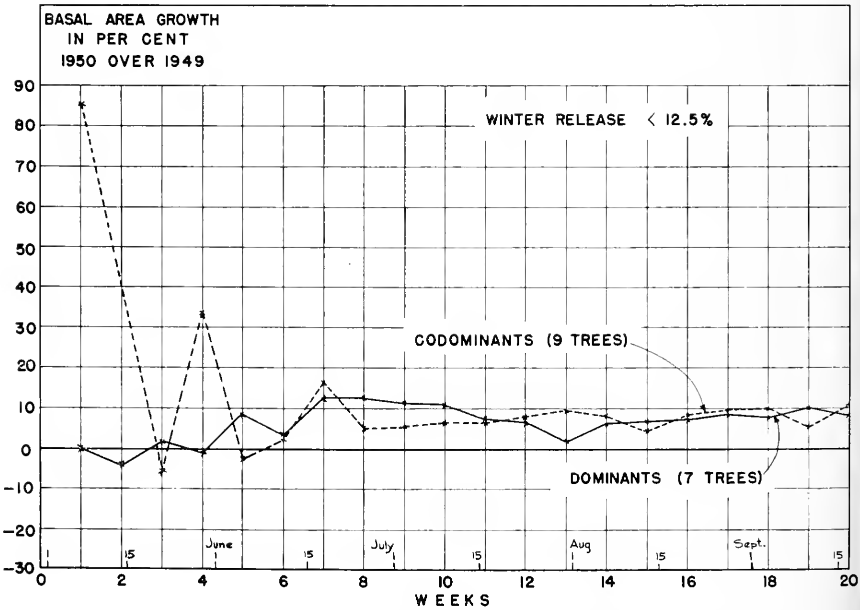

FIGURE 52. Percentage weekly basal area growth of dominant and codominant trees given winter release of less than 12.5 per cent.

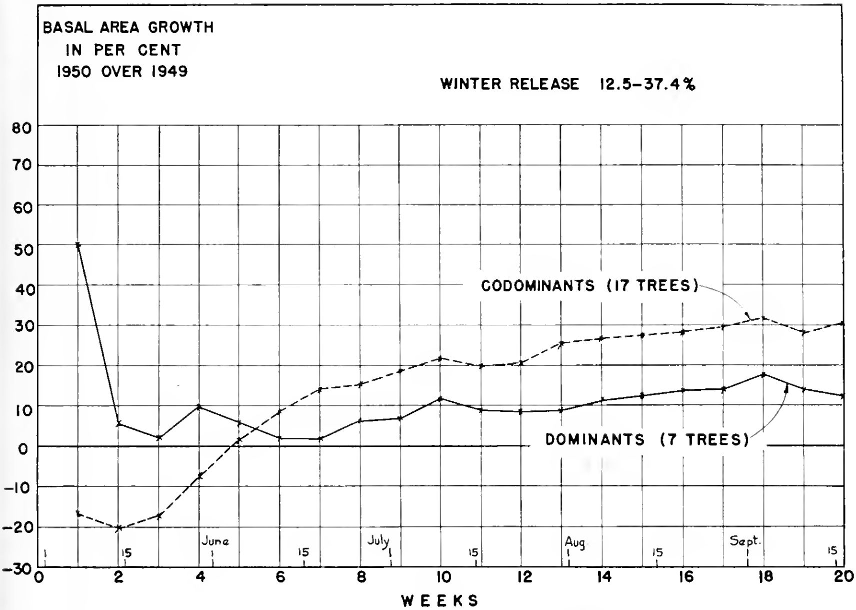

FIGURE 53. Percentage weekly basal area growth of dominant and codominant trees given winter release of 12.5-37.4 per cent.

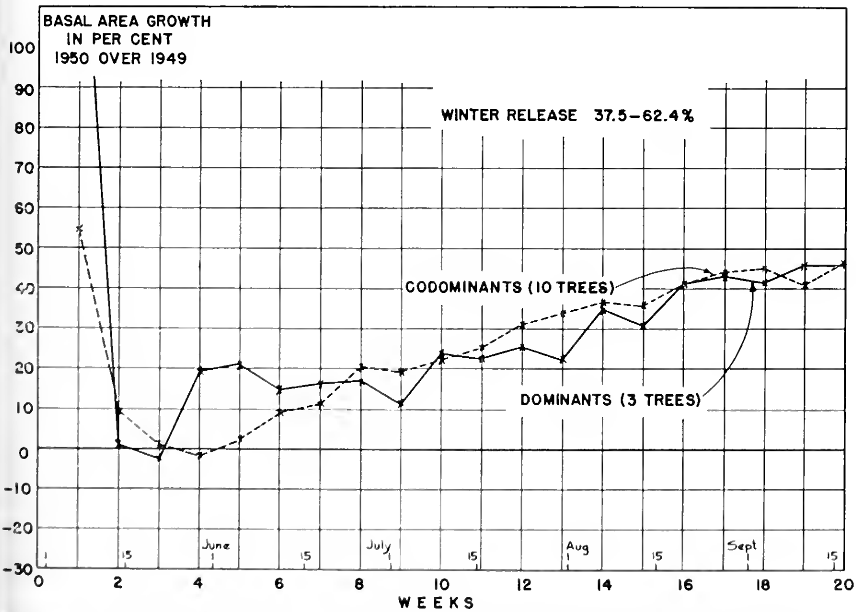

FIGURE 54. Percentage weekly basal area growth of dominant and codominant trees given winter release of 37.5-62.4 per cent.

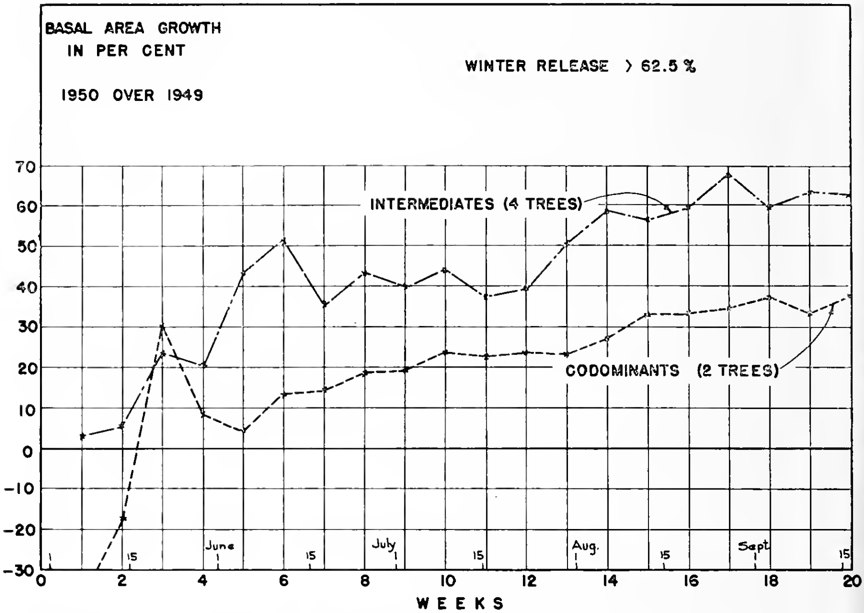

FIGURE 55. Percentage weekly basal area growth of codominant and intermediate trees given winter release of more than 62.5 per cent.

which in this case for both crown classes was nearly 7 per cent of the crown surfaces, is too small to make much difference.

In the present instance, both crown classes increased only about 10 per cent on basal area growth over the 1949 growth. The additional light to which the crowns are exposed is too small to register a real increase. In this case, where both dominant and codominant trees received a 7 per cent crown release, most of this release took place on the lower part of the crown. On larger trees this part of the crown is rather shallow. Therefore, only relatively few leaves will receive added light. The larger percentage increase in the other figures for codominant over dominant and intermediate over codominant, may take place because the intermediate trees have been growing in comparatively greater partial shade than the codominant trees. Thus, when a certain percentage of the crown is released, the side of the crown will not alone be benefited by the additional light, but the rest of the crown will receive more light as well, since the crowns of intermediate trees are smaller than those of the codominant trees. The same explanation also can be applied to the comparison between the codominant and dominant trees for greater percentage releases. Generally, it may be safe to assume that the lower crown classes have their crowns in deeper

shade than the higher crown classes. This will mean that the leaves of the lower crown class trees assimilate under a relatively lower light intensity compared to the leaves of the higher crown classes. Therefore, any increase in light intensity for the leaves of the lower crown classes will give greater increase than for the higher crown classes, since the former leaves will assimilate at a rate farther below their maximum capacity than leaves on higher crown class trees.

Figures 56, 57, and 58 show the relationships between the different crown classes that have been exposed to the same percentage summer release. The trend in these figures is the same as occurred for the winter releases of similar percentages. Again there is little difference in the growth increase of dominant and codominant trees that have been exposed to less than 12.5 per cent crown release. For a crown release of 12.5 to 37.4 per cent, the codominant trees show much greater increase on basal area growth than the dominant trees. Likewise, for a summer release of the crowns of 37.5 to 62.4 per cent, the intermediate trees have increased relatively more than the codominant trees.

The fact that the intermediate trees increase relatively more than the codominant trees, and that the codominant trees increase correspondingly more than the dominant trees after the same amount of release, is very encouraging. This will mean that for yellowpoplar

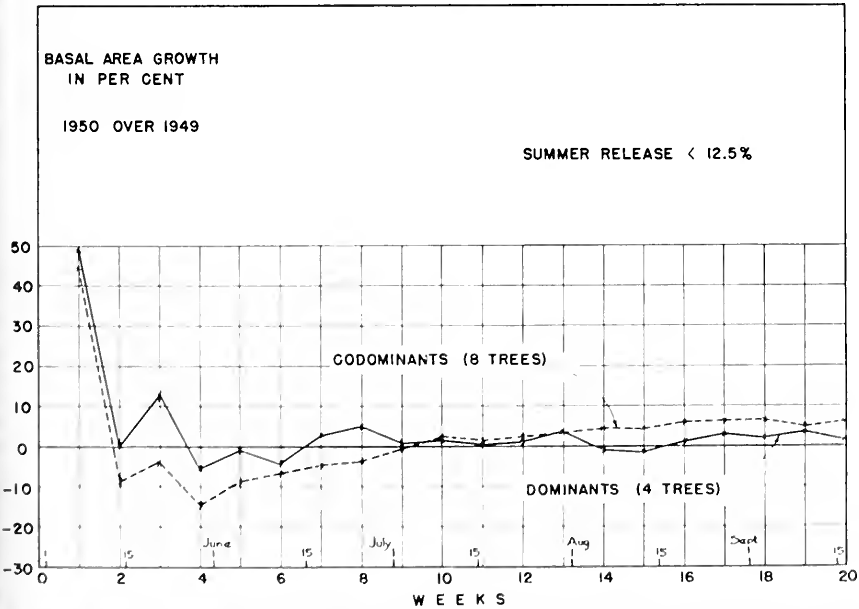

FIGURE 56. Percentage weekly basal area growth of dominant and codominant trees given summer release of less than 12.5 per cent.

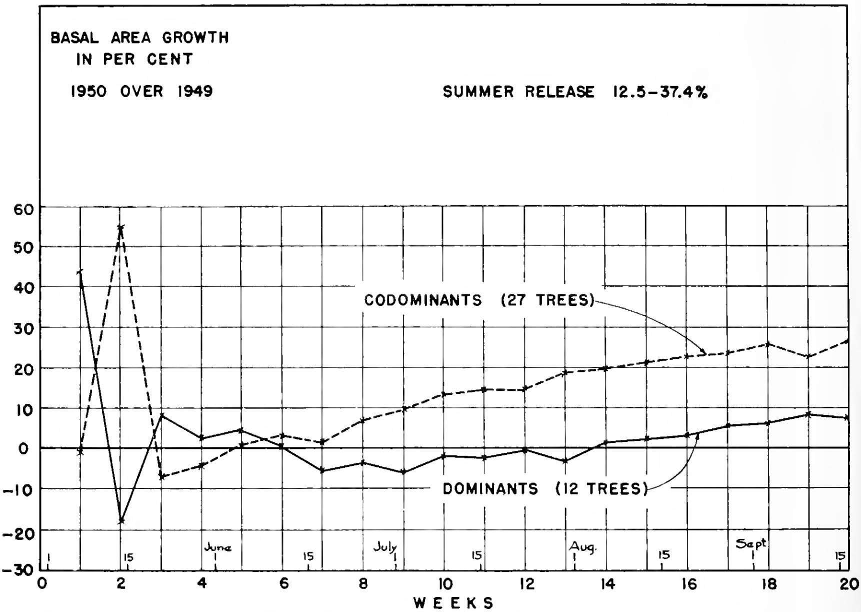

FIGURE 57. Percentage weekly basal area growth of dominant and codominant trees given summer release of 12.5-37.4 per cent.

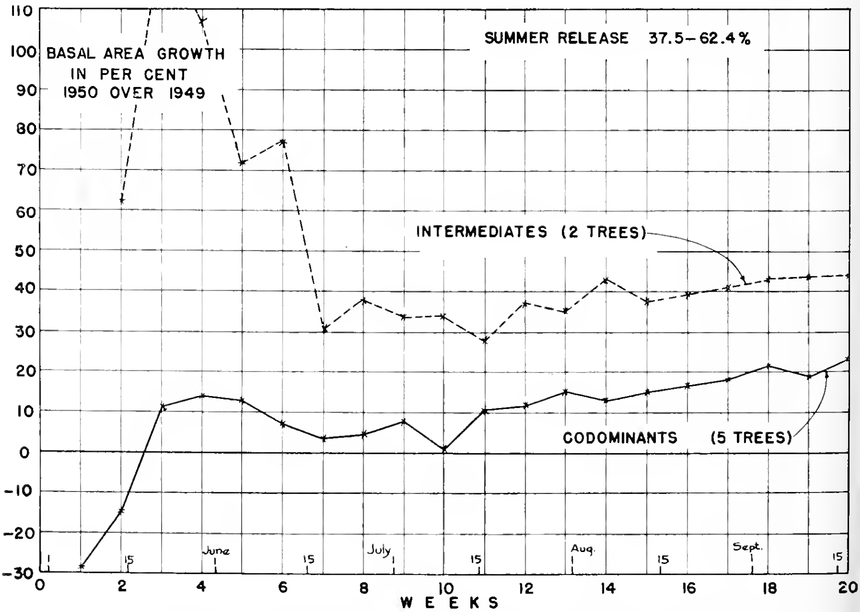

FIGURE 58. Percentage weekly basal area growth of codominant and intermediate trees given summer release of 37.5-62.4 per cent.

and perhaps other species, a very favorable reaction will be obtained if in thinnings the lower crown classes are favored. It is possible to get a greater percentage increase, and often it also may be possible to place the growth on stems that will have a greater potential value because of less defects from dead branches and hidden knots. These factors indicate that the Borggreve (2) system of thinning from above may be used successfully in yellowpoplar stands.

In general, the above analyses and discussions show that the more percentage crown release a tree receives, whether it be during the dormant or during the growing season, the more it will increase in growth on the basal area. Furthermore, the graphs show that if the release is made during the domant season, the increased basal area growth will begin early in the growing season. For more complete releases, the increased growth can be recorded as early as the third or fourth week of the growing season. For trees that receive crown releases during the growing season, the reaction will be immediate if these releases are rather complete. For less complete releases, the increased basal area growth will not be recorded until a few weeks after the release takes place. In no case has there been any evidence of shock reaction, although some of the trees received a crown release of more than 87.5 per cent.

It also is interesting to note that for the same percentage release, the lower crown classes will show a greater percentage increase of basal area growth than the higher crown classes. In general, for the same percentage release, a codominant tree will increase more percentagewise in basal growth than a dominant tree during the growing season immediately after the release has been made. In the same way, an intermediate tree will grow more in percentage than a codominant tree.

Statistical Analysis

For the purpose of determining the validity of the results, *t*-tests were made for each of the classifications between the growth during 1949 before the release was made and the growth during 1950 after the crowns had been released. The 1950 growth was corrected by means of control trees of the same crown classification as the trees that were analyzed.

Table I shows that the greatest significance is obtained for the winter releases, since these will show larger differences on basal area growth between the two growing seasons than the summer-released trees. Owing to the small number of samples in the dominant classification, and since the difference between the growth during the two seasons in this classification is not as great as in the codominant and

Table 1. Statistical Analysis of Winter and Summer Release Classifications

Classifications	Dominant		Probability of error less than	Codominant		Probability of error less than	Intermediate		Probability of error less than
	N	t		N	t		N	t	
Winter									
			%			%			%
Less than 12.5%	7	1.617	20	8	4.219	1	—	—	—
12.5%—37.4%	7	2.442	5	17	7.133	1	—	—	—
37.5%—62.4%	3	1.371	30	10	4.399	1	2	6.429	5
62.5%—87.4%	—	——	—	2	1.778	30	4	3.910	2
All trees	17	2.802	2	37	8.941	1	6	3.201	2
Summer									
Less than 12.5%	4	.123	—	8	.715	50	—	—	—
12.5%—37.4%	12	1.598	20	27	4.596	1	2	2.167	20
37.5%—62.4%	—	——	—	5	4.597	1	2	8.657	2
62.5%—87.4%	—	——	—	4	2.615	10	—	—	—
More than 87.5%	—	——	—	—	——	—	2	2.704	20
All trees	16	1.261	30	44	5.387	1	6	4.386	1

intermediate classifications, the t values do not indicate real differences. In the codominant classification, which was represented by more sample trees, most of the t values are satisfactory. Lack of data in the intermediate classification causes too small values of t. It may be assumed, however, that if more sample trees had been available in all classifications, satisfactory values of t could have been obtained in most of the classifications. This is indicated by the ts obtained from the "all trees" classifications, which show a generally higher probability.

Form Changes After Release

From the foregoing, it is evident that a considerable increase in basal area growth takes place after releases have been made of the sample trees. It might be suggested that most of the changes take place on the lower part of the stem and that this will improve the structural design of the tree, thereby making it more wind resistant. If that were the case, it would mean that the form quotient, the relation of the diameter at half height of the tree divided by diameter breast high, would be smaller. If this happened, the increased rate of basal area growth might not mean an appreciable amount of volume growth.

In order to investigate these relationships, a stem analysis was performed on tree No. 101. This tree was released during the winter of 1941-42 when another yellowpoplar, standing five feet from it, was cut. The crown release was approximately 40 per cent. In 1950, tree No. 101 had the following dimensions:

Diameter breast high	16.4 in.	Crown projection	450 sq. ft.
Total height	88 ft.	Crown surface	1,116.3 sq. ft.
Dead length	40 ft.	Crown diameter	23.9 ft.
Clear length	40 ft.	Crown length	20 ft.

The tree did not receive any release after the cutting made in 1941-42 and was not in any way released during the experiment, in which it was used as a control. Figure 59 shows the form of the part of the stem extending up to 57 feet above the ground. The curves indicated are the dimensions inside bark in 1932, 1941, and 1950, showing the form of the tree 9 years prior to the release and 9 years after the release. The graphs show that no appreciable change in form has taken place during the last 18 years. The following figures will show the form in more detail:

	1950	1941	1932
D.B.H. inside bark	14.66	11.88	9.54
Diameter 17 feet above ground	13.08	10.70	8.70
Diameter 44 feet above ground	10.10	8.05	6.10
$\frac{\text{Diameter 17 feet}}{\text{D.B.H.}}$	89.2	90.0	91.2
$\frac{\text{Diameter 44 feet}}{\text{D.B.H.}}$	68.8	67.7	63.9

This indicates that although there has been a slight decline of the proportion between the inside diameter at the top of the first 16-foot log divided by d.b.h.—the so-called Girard Form Factor—there has been an increase in the regular form quotient. This last one is based on the diameter inside bark at half the height of the tree in proportion to the diameter breast high. The conclusions from these calculations must be that if any change in form has taken place, it has been towards a form that is closer to the cylinder compared to what it was before thinning.

In the left part of Figure 59 is shown the total diameter growth in inches for the 9-year period before release and the 9-year period after release. It is evident that the total diameter growth at various

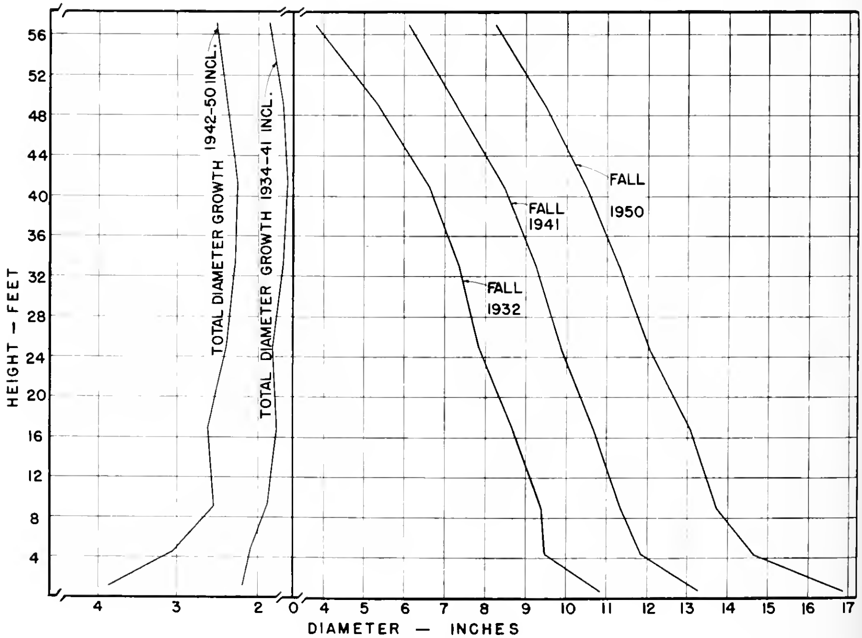

FIGURE 59. Stem analysis of Tree No. 101.

points of the stem has been much greater during the period after release than in the period before release. For some reason, the diameter growth 1 foot above ground has increased proportionally more than any of the other diameters. Otherwise, the increase has been rather even throughout the stem, with a percentage increase for the last 9 years over the 9 years previous to the release varying from 29.9 at 25 feet above the ground to a maximum of 47.5 per cent at 17 feet above the ground. The percentage increase at breast height was 43.8, considerably less than the maximum increase.

It is realized that an analysis of only one tree cannot give conclusive results, but since no other trees were available which had received a release several years before, it was not possible to supplement the foregoing analysis with more data. Based on the measurements listed above, however, there are indications that the diameter at various points of the stem will increase at about the same rate as will the diameter at breast height. If this be true, and there are no reasons to believe differently, the measurements given for basal area growth also will be indicative of volume growth.

It is interesting to note in Figure 60, which shows the basal area growth of the same tree discussed above, that there is an increase on the entire tree during the first growing season immediately after

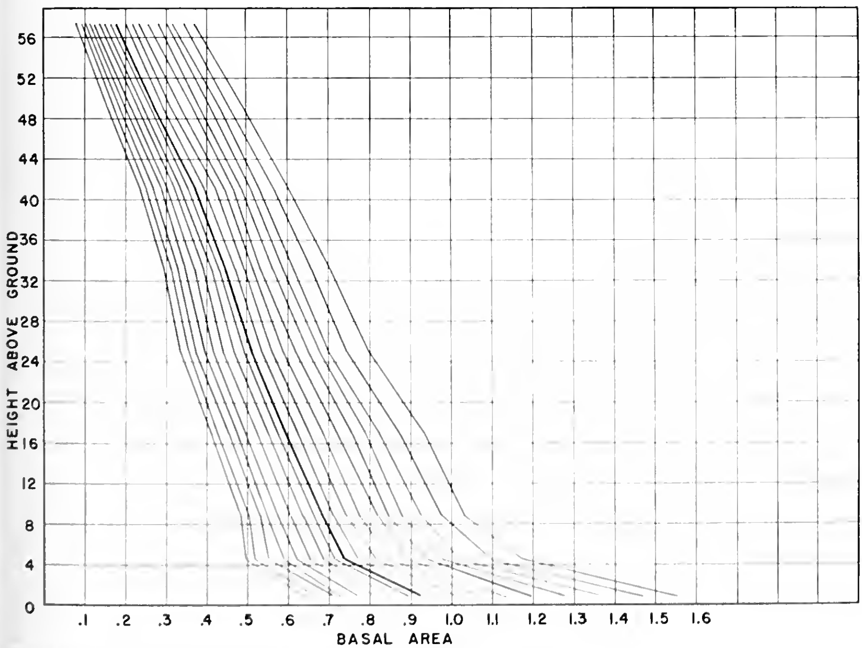

FIGURE 60. Basal area stem analysis of Tree No. 101.

release. This basal area increase gets progressively greater as the tree grows. The explanation for this may be found in a statement on assimilation by Heinicke and Childers (12): "Much of the leaf surface, probably more than 90 per cent of the total, is functioning at a very low rate on many days during the season." This will mean that immediately after a tree is released, additional light will be available to many of the leaves. The additional light will enable the leaves to produce at a greater rate than before. During the following years the crown will have opportunity to expand because of the open space available after some of the competition for light has been lessened by cutting a neighboring tree. With the expansion of the crown, more leaf surface will be available for increased production. This shows up in the increasing rate of growth as seen in Figure 60.

The varying amount of assimilation of the individual leaves, which is caused by differences in available light, may be the reason for the spread of the individual data in the relationship between basal area growth and crown surface shown in Figure 11. Although a rather high correlation index was obtained for this relationship because the trees included had not been released during the last ten years, differences in light intensities for different parts of the crown may have caused much less assimilation on the more shaded trees compared to the more dominant trees with the same crown surface. Although, in general, crown surface is a good indicator of basal area growth, crown surface may show a considerable spread of the data if the measurements had been taken in a stand in which some trees had been released more than others.

Differences in Radial Growth on the Same Tree

When measuring radii at breast high on tree No. 101 to obtain data for the stem analysis, it was noticed that these varied considerably. Further investigation revealed that on some trees with several dendrometer stations, the difference in growth in some cases was as great as 50 per cent at breast height.

Since it is sometimes believed that crown development and radial growth are related in such a way that the side of the stem that is under the largest crown development grows faster, measurements from dendrometer stations for the growing season of 1949 were compared with the crown radius directly above the station on trees that had several dendrometer stations. The radial growth for 1949 from these stations was plotted over the crown radius directly above the station, but no significant correlation was found. This shows that for the sample

trees investigated, the uneven crown development does not have any influence on the radial growth of the tree.

Another hypothesis that has been mentioned is that trees grow faster on the northern side because of the presence of more moisture, which supposedly should create greater radial growth. To check this possibility, the radial growth for 1949 was investigated on trees that had four micrometer stations placed in the cardinal directions of north, east, south, and west. The basal area growth for 1949 for each of the directional dendrometer stations was plotted over diameter breast high measured with diameter tape. The data showed no relationship and the averages of the values for radial growth for 1949 for the different directions were about the same. This indicated that no radial growth related to cardinal compass directions grew faster than any other one.

Finally, the 1949 basal area growth was calculated on the basis of one radius for each tree with several stations in such a way that the stations were grouped in relation to whether or not they were located over the largest root extending from the tree, the second largest root, or no root. The basal area growth was related to the crown surface. Figure 61 shows the three curves resulting from this investigation. The

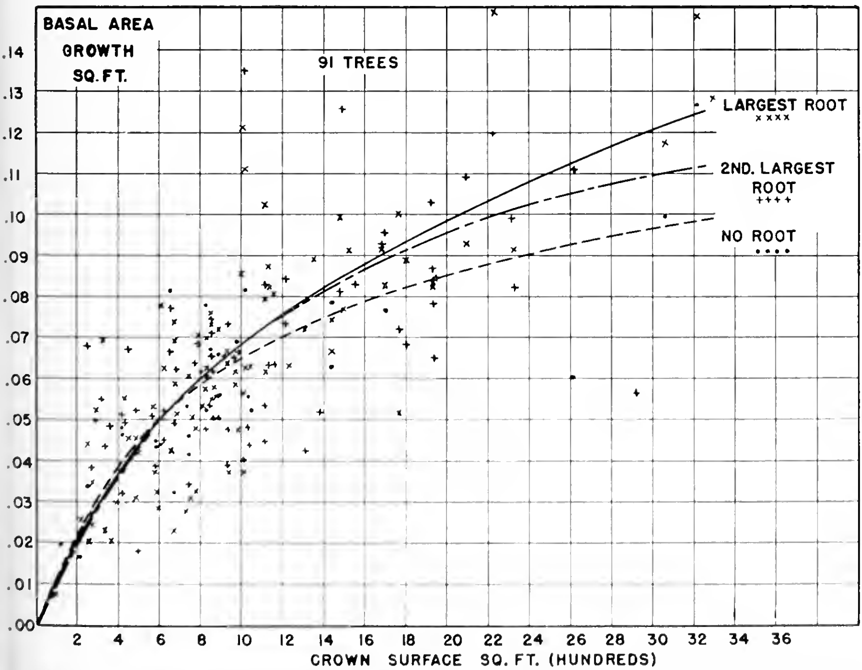

FIGURE 61. Basal area growth based on different radial growth related to tree roots.

curve for basal area growth, determined by radial growth over the largest root, has a correlation index of .803. The curve for basal area growth over the second largest root has a correlation index of .592, whereas the curve for basal area growth over no root has a correlation index of .803. Up to 800 square feet of crown surface there is no difference between the three curves. For the larger crown surfaces, however, there are considerable differences between the three curves.

For the purpose of determining growth of stands by taking increment borings from sample trees, it is of importance to take these in the same relative position as roots that extend out from the trees. Otherwise, a considerable variation may be included in such measurements. This would establish considerable inaccuracies in prediction of growth of stands.

For the purpose of determining how far up the stem this influence of the roots extends, a stem analysis was made of tree No. 101, which was cut down after the 1950 growing season. By plotting the radii over the largest root, the second largest root, and over a place from where no roots extended, the measurements at breast height showed that during the last 9 years the radius above the largest root had grown 1.7 inches, and the radius over no root had grown 1.4 inches. At a point 9 feet above the ground, the effect of the roots had diminished. At that point the radial growth above No. 1 root for the last nine years was 1.25 inches, over No. 2 root 1.3 inches, and above no root 1.2 inches. Farther up the tree no relationship was found between the roots and radial growth.

Light Intensity and Root Competition

For the purpose of perhaps throwing some light on the question of which factor or factors are causing the increased growth after the trees are released, a separate experiment was established. The thought occurred that if instead of cutting the neighboring trees, these were only bent away from the sample tree, this tree would receive as much light as if the surrounding trees had been cut. On the other hand, if there was any interference from root competition, this would still be present. Unfortunately, the yellowpoplar that were used in the experiment were so large that it was impossible to bend them away from the neighboring trees. To get a little information on this problem, however, such an experiment was established in a hybrid poplar plantation.

These hybrid poplar were planted as cuttings in 1941, but had been cut down to obtain cuttings for planting stock. In 1943 they

were allowed to grow up. At the time of the experiment they had a diameter of between 4 and 5 inches and a height of 25 feet. Since the plantation is very small, it was possible to establish only 2 trees of each category—2 for control, 2 to be released by thinning, and 2 by bending the neighboring trees. One dendrometer station was established on each of the trees. Measurements were taken throughout the 1949 growing season without disturbing the growing conditions of the trees. During the dormant season of 1949 and 1950, all trees that were interfering with the crown development of 2 of the trees were cut. For 2 other trees the interfering ones were bent away and held in that position by ropes during the entire growing season of 1950. The 2 control trees were not disturbed. The selection of the individual tree for any of these classifications was made arbitrarily.

When the plantation was established by cuttings, it was done on a 3 by 3 foot spacing. After it was allowed to grow in 1943, it became very crowded and was released to a 6 by 6 foot spacing in 1946. Since then no more cutting was made in the stand up to the time of the experiment. Therefore, the trees were quite crowded and exerted considerable interference on each other. Not until the results of the control trees became available, however, was it realized that the stand was actually stagnating. As can be seen in the lower part of Figure 62,

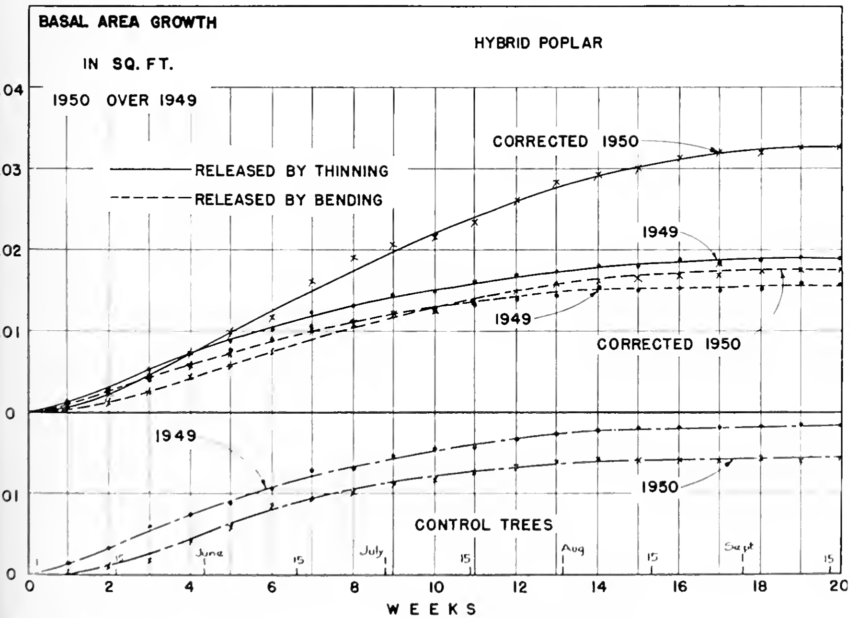

FIGURE 62. Weekly basal area growth of hybrid poplar.

these trees have grown considerably less on the basal area during 1950, compared to the growth during 1949, even though the yellowpoplar that were growing in close proximity to the hybrid poplar showed considerably greater growth on the control trees during 1950 than in 1949. The upper part of Figure 62 shows the comparison between the corrected growth of 1950 and the growth of 1949. The growth of 1950 was corrected on the basis of difference in growth of the control trees during the two growing seasons, just as was done for the yellow-poplar experiment. In Figures 62 and 63, it can be seen that the trees that were released by cutting the neighboring trees have increased considerably after release, whereas those which were released by bending away neighboring trees have increased only slightly. Although the result from this experiment by no means can be termed conclusive, owing to the small number of sample trees, it may show some trend that can be interpreted in this way: root competition shows considerable influence where the trees grow close together. In such places, even if the soil is moist and well-drained, the limiting factor seems to be root competition rather than crown interference.

Profitable Tree Forms

In order to conduct intensive silviculture management, it is necessary to have an intimate knowledge of the growth and reactions of the individual tree. During the last 150 years, volumes have been written about forest stands, their volume per unit, the average diameter, and their reproduction. Little, however, has been studied about the single tree, the proportion of its crown to the total height, the number of clear logs it should have in order to produce the best value in the shortest time, its reaction to release of varying degree, and the compound interest rate with which it grows during the stages of its development. In recent years an interest in these matters has occurred through the work of Biolley (1), Mundt (10), Muus (20), and others. It is strange, however, that this interest has not taken form in writing before, since as early as 1818 Reventlow (25) wrote about oak and beech in Denmark as follows: "It must be assumed that the rotation of oak should be determined by the time it takes to produce heavy timbers providing that these will yield favorable prices. The owner will then be fully compensated for having the trees beyond the time when the volume increment drops below 4 per cent interest compared to the volume of the tree. However, for beech the main object will be to grow fire wood. Therefore, the rotation should be determined by the time at which the annual growth be less profitable than the interest of the capital vested in the tree."

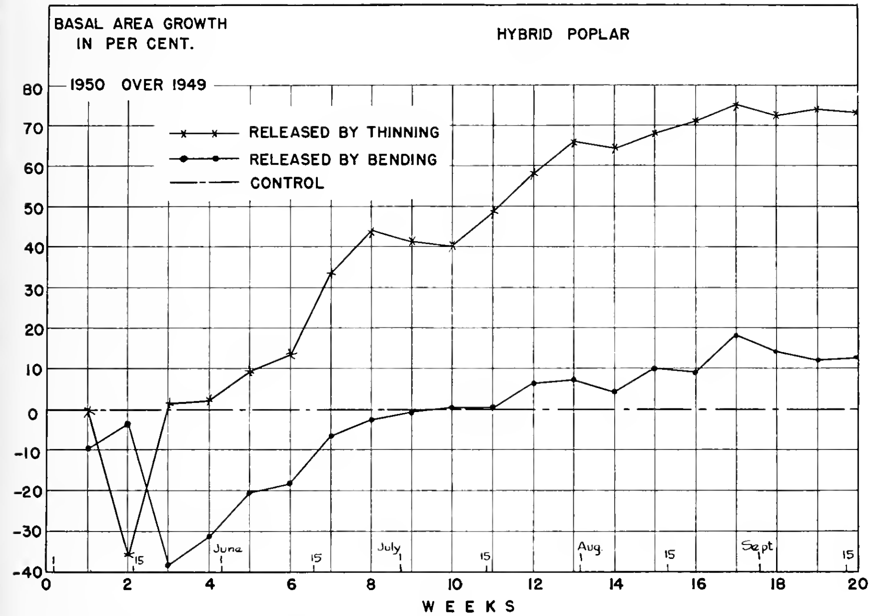

FIGURE 63. Percentage weekly basal area growth of hybrid poplar.

This definition and direction for silvicultural management is as modern as if it were written today. In order to conduct profitable silvicultural management, the compartments and area units cannot yield a profit unless the individual tree yields an interest rate equal to the interest that could be obtained on other capital investments. Not until each unit yields a profit will the whole forest produce its maximum interest rate on the invested capital.

In a former publication (14), various relationships for yellowpoplar were presented, such as total height and age, total height and crown length, total height and crown diameter, total height and diameter breast height, and total height and clear length. Besides these, ten years basal area growth for the individual tree was related to crown length and crown diameter. Finally, a table showing the compound interest rate of periodic growth for various diameters breast high was constructed from the lumber grades sawed from logs of sample trees whereby the value of the individual tree was obtained. The total height, rather than age, was used as an entry to all curvilinear relationships for the dimensional measurements of the tree, since the age is not as indicative as total height when the general development of a tree is being discussed. Furthermore, using total height as a basis will more or less do away with the necessity of taking into consideration

different site indices for the growing places of yellowpoplar. From a study by Møller (21), showing the growth of beech on five different site indices, it can be seen that for the same total height, the diameter breast high, basal area, and volume are almost the same for each site index class.

Since it is possible to create the most profitable forms of yellowpoplar by releasing their crowns and since, based on the present findings, these releases can be made by relatively few cuttings effecting more or less complete releases without creating unfavorable growth reactions, it is considered of interest to investigate how the individual tree should be formed in order to produce the highest possible interest rate throughout its life. In the Appalachian region the most favorable diameter breast high for logging purposes is considered to be between 24 and 26 inches. This is due to the terrain and the capacity of the average saw mill. Such trees will produce a large amount of high-grade lumber. Also, their size will be more favorable in logging costs per thousand board feet, compared to both smaller and larger dimensions. Furthermore, to produce these dimensions profitably, the individual tree should maintain a compound interest rate throughout its life of more than 6 per cent. To investigate the radial growth of a 24-inch tree growing 6 per cent compound interest per year, Table 2 from an earlier publication (14) is used.

In Table 2 it can be seen that if a 24-inch tree is to produce 6 per cent compound interest, it will have to have a radial growth of about 1.8 inches during the last ten years. From the charts available in *Profitable Tree Forms of Yellowpoplar* (14), it will be found that to have such a growth the tree will have to have a crown length of close to 70 feet, which for a total height of 100 feet will leave two 16-foot logs in clear length. From the curve giving the relationship between crown length and crown diameter, the corresponding crown diameter was found. If a 100-foot tree is to have 33 feet of clear length, it is necessary to maintain live crown above 33 feet from the time this clear length is established. From the curve showing the relationship between total height and crown length, it will be seen that at a total height of 60 feet the crown length is about 28 feet. From then on no more clear or dead length should be established. Therefore, the relationship between total height and crown length will increase from this time on. This is shown in Figure 64. Through adequate thinnings such a crown length can be developed.

By means of the relationship between crown length and basal area growth during the last 10 years, it is now possible to construct Table 3. Starting with a tree 40 feet tall that, according to the relationship between total height and d.b.h., has a diameter of 7 inches

Table 2. Compound Interest Rate of Periodic Growth

D.B.H.	Growth Rates (Represent 10 years' growth on radius)												
	.4 in.	.6 in.	.8 in.	1.0 in.	1.2 in.	1.4 in.	1.6 in.	1.8 in.	2.0 in.	2.2 in.	2.4 in.	2.6 in.	2.8 in.
	%	%	%	%	%	%	%	%	%	%	%	%	%
12	2.2	3.4	4.5	5.9	7.1	8.4	9.6	10.9	11.6				
14	2.0	3.1	4.2	5.4	6.5	7.5	8.5	9.5	10.8				
16	1.8	2.8	3.8	4.9	6.0	6.9	7.9	9.0	10.0	11.0	11.9		
18	1.7	2.6	3.5	4.5	5.5	6.3	7.2	8.3	9.4	10.4	11.4	12.4	
20	1.5	2.3	3.1	4.0	4.9	5.7	6.6	7.6	8.6	9.6	10.6	11.6	12.5
22	1.3	2.0	2.8	3.6	4.4	5.1	6.0	6.8	7.7	8.6	9.7	10.6	11.5
24	1.2	1.8	2.5	3.2	3.9	4.6	5.4	6.1	6.9	7.7	8.5	9.4	10.3
26	1.0	1.5	2.1	2.7	3.3	4.0	4.7	5.3	6.0	6.6	7.3	8.1	8.8

Based on trees that will have two clear logs and 46.4 per cent crown at 20 inches d.b.h.

Table 3. Progressive Development of Yellowpoplar Trees Maintaining a Compound Interest Rate of 6 Per cent or More Until a 24-inch D.B.H. Has Been Reached

Total Height	Age	D.B.H.	Crown Length		Crown Diameter	Basal Area	Volume Board Feet (International)	10 Years Growth		Compound Interest Rate
			Feet	Per cent				Diameter	Basal Area	
feet	years	inches			feet	sq. ft.		inches	sq. ft.	%
40	14	7.0	18	45	5	.267	—	—	—	—
50	19	8.5	22	44	9	.394	—	2.9	.27	13.9
60	25	10.6	27	45	20	.613	30	3.5	.35	12.8
70	32	13.5	37	53	30	.994	110	4.1	.52	11.3
80	41	17.2	47	59	39	1.614	300	4.1	.67	9.8
90	55	22.4	57	63	47	2.737	622	3.6	.81	6.7
100	84	33.6	67	67	53	6.157	1390	2.6	.92	1.0

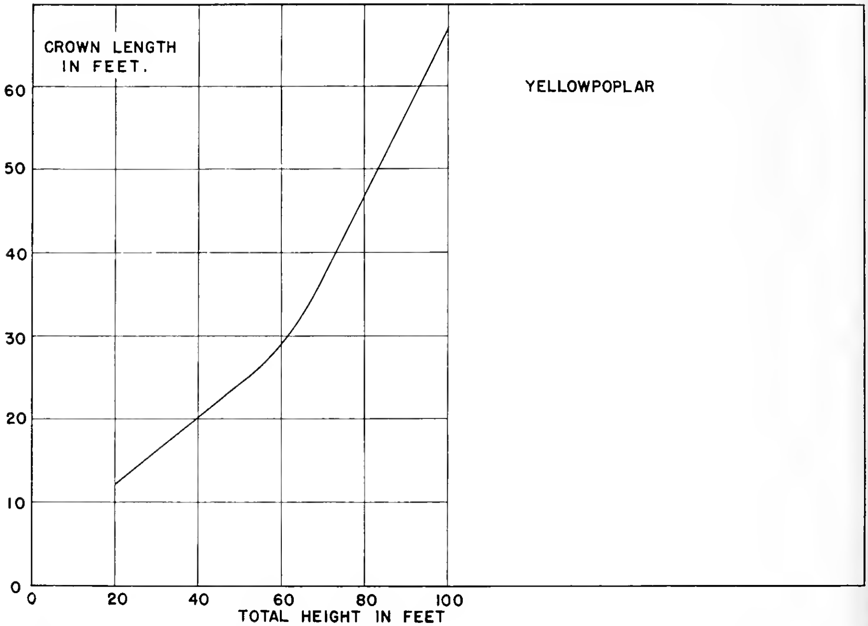

FIGURE 64. Relationship between total height and crown length.

and which, according to the total height and age curve, is 14 years old, the basal area growth for 10 years is added to this diameter. This gives the d.b.h. at 24 years. From this, the d.b.h. for a tree 50 feet tall and 19 years old is found to be 8.5 inches. Again, the basal area growth for 10 years, based on the corresponding crown length, is added to the diameter. Through this the d.b.h. for a tree 60 feet tall and 25 years old is found. The calculations for the total heights in Table 3 are made in similar ways.

From the results in Table 3, Figures 65 and 66 have been constructed. They show the development of the single tree for various total heights. It will be seen that with increasing age and d.b.h, there is a corresponding decrease in the compound interest rate. At a total height of 92 feet, the d.b.h is about 24 inches and the compound interest rate is 6 per cent. These curves may serve as a guide for the forest manager. By taking a few simple measurements, he will know if the individual trees need more space in order to conform with the rates of development shown in these figures. If the development of the individual trees can be made according to these figures, he will know that each tree is returning an adequate compound interest rate on the capital in form of value invested in the individual tree.

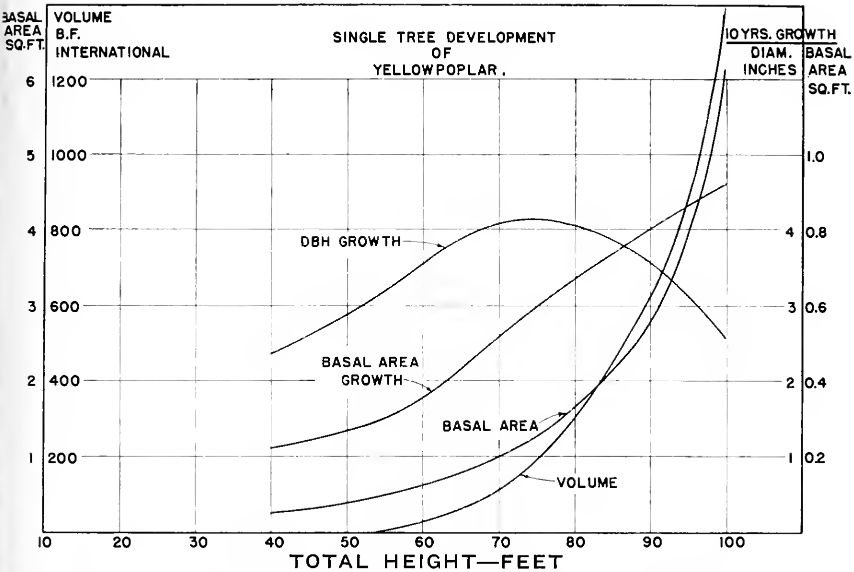

Figure 65. Dimensional optimum development of yellowpoplar.

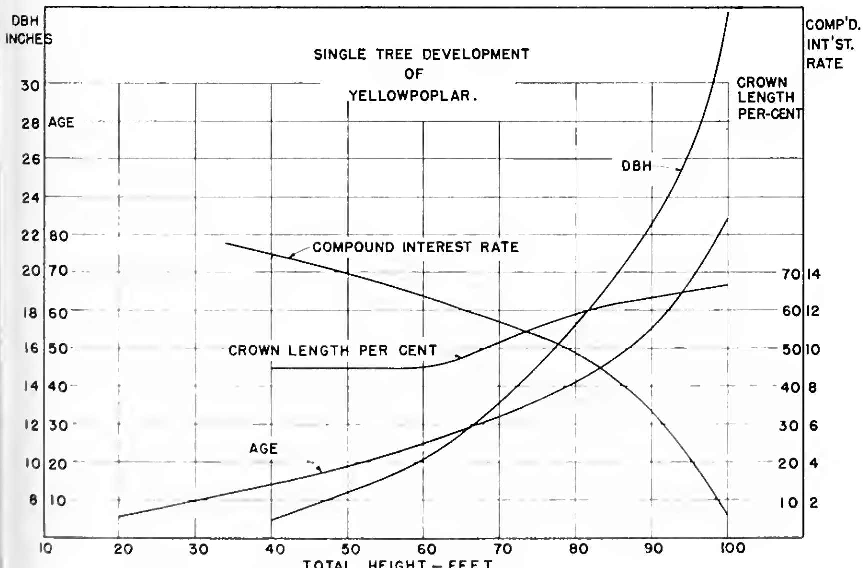

Figure 66. Dimensional optimum development of yellowpoplar.

General Conclusions

As was mentioned previously, many European foresters recommend light but frequent thinnings. In Denmark, where the forests are managed intensively, foresters advocate that seldom should more than 12 to 15 per cent of the volume be removed during any thinning. Normally such thinnings are made in the younger stands, with three to four-year intervals. In the older stands the intervals may be five to seven years. Two main reasons are given for these light thinnings: (1) if heavier cuttings were made, the trees would receive a shock and stagnate for a few years; and (2) the soil may deteriorate and a heavy matting of grass will cover the ground. This latter occurrence is mainly due to the rather heavy and poorly drained soils.

In this country, light and frequent thinnings will be profitable only where the markets for small-dimensioned materials are exceptional and where the forest areas are exceedingly accessible. Generally, light thinnings with three-year or four-year intervals, which yield little volume per acre, will not make profitable operations. The alternative has been for foresters to interest owners in making periodic thinnings with longer intervals. Such cuttings may not be ideal in many ways. The most serious drawback to such infrequent thinnings is that the remaining trees will have to be liberated to a considerable extent if they are not to crowd each other before the next thinning. A crowded position before the next thinning would cause the lower branches to die. This would increase the dead length and cut down on basal area growth. The soil deteriorating effect of heavier cuttings does not seem to be a serious problem in this country. Herbaceous vegetation may increase after a heavy thinning, but a heavy grass sod is seldom established in the forest. After the stand closes up, this vegetation will again subside and not cause any ill effect on the soil condition.

As a general directive to silvicultural management of hardwood stands, particularly yellowpoplar stands, it seems reasonable to believe, according to the findings reported above, that heavy thinnings will not have any retarding effect on this species but, on the contrary, cause an increasing amount of growth on basal area on individual stems corresponding to the release. Therefore, it is possible to make thinnings that will remove between 30 and 40 per cent of the volume in each cutting. Such thinnings will increase the basal area growth on the remaining trees and considerably shorten the rotation age of the individual tree. Furthermore, such thinnings not only will increase the growth on the remaining trees, but also will develop wood with higher specific gravity and more strength, as reported by Erickson (9). Thinnings

of this severity might have to be done only at eight-year to ten-year intervals to prevent the crowns of the remaining trees from interfering too seriously with each other and thereby retard the diameter growth. Such thinnings are likely to be made in many parts of this country, because by cutting out more volume than would be done through more conservative methods, they will have a better chance to produce a profit from each of the cuttings wherever there are markets for small-dimensioned materials such as pulpwood, mine props, and fire wood.

Summary

Since the amount of material removed in each thinning is closely related to the economics of such an operation, and since foresters marking for thinning are constantly confronted with the question of how much crop trees should be released, this experiment was established to study the reaction of various degrees of release on individual remaining trees.

A micro-dendrometer was used to measure weekly radial growth on 193 sample trees of yellowpoplar during the 1949 and 1950 growing seasons. During the dormant season, the crowns of 68 trees were released from less than 12.5 per cent to more than 75 per cent. A similar release was made for 67 trees during the 1950 growing season after no further change took place in the cell structure of either light or shade leaves. Fifty-one trees were maintained as controls.

Through these investigations, it was found that yellowpoplar reacts favorable to release of the crown, varying from 12.5 per cent to more than 75 per cent, made both during the dormant and the growing season.

The reaction to release during the dormant season was noticeable by the fifth or sixth week of the growing season. The increase in basal area growth corresponded to the percentage of the released crown surface.

The sample trees were divided into the conventional crown classes of dominant, codominant, and intermediate. No retarding effect of the sudden and drastic release of the crown was found for any of the crown classes.

For the same percentage crown release, it was found that intermediate trees would show a greater percentage increase in basal area growth than codominant trees. Codominant trees in turn would increase more, on a percentage basis, on basal area growth than dominant trees receiving the same percentage release of the crowns.

A stem analysis was made of a tree released 9 years ago. A comparison of the form of the tree 9 years before release, at the time

of release, and 9 years after release, indicated that the form factor had improved. This indicates that the increased basal area growth also may express an increase in volume.

Using analyses of the results obtained, together with the findings given in a former publication (14), recommendations have been made for growing the individual tree in such a way that it will maintain a compound interest rate of 6 per cent until it has reached a d.b.h. of 24 inches. A table has been constructed giving dimensional figures for the tree during its different stages until it reaches maturity.

The possibility of favorable response to drastic releases of crown surfaces makes it possible to practice intensive management on young stands that are not able to produce enough volume from light thinnings to make such operations profitable.

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Appendix

Basal Area in Square Feet

D.B.H.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
					2.00—2.99 Inches D.B.H.					
inches										
2.0	.0219	.0220	.0223	.0225	.0227	.0229	.0231	.0234	.0236	.0238
2.1	.0241	.0243	.0245	.0247	.0250	.0252	.0255	.0257	.0259	.0262
2.2	.0264	.0266	.0269	.0271	.0274	.0276	.0279	.0281	.0284	.0286
2.3	.0289	.0291	.0294	.0296	.0299	.0301	.0304	.0306	.0309	.0312
2.4	.0314	.0317	.0319	.0322	.0325	.0327	.0330	.0333	.0336	.0338
2.5	.0341	.0344	.0346	.0349	.0352	.0355	.0357	.0360	.0363	.0366
2.6	.0369	.0372	.0374	.0377	.0380	.0383	.0386	.0389	.0392	.0395
2.7	.0398	.0401	.0404	.0407	.0410	.0413	.0416	.0419	.0422	.0425
2.8	.0428	.0431	.0434	.0437	.0440	.0443	.0446	.0449	.0452	.0456
2.9	0459	.0462	.0465	.0468	.0471	.0475	.0478	.0481	.0484	.0488
					3.00—3.99 Inches D.B.H.					
3.0	.0491	.0494	.0497	.0501	.0504	.0507	.0511	.0514	.0517	.0521
3.1	.0524	.0528	.0531	.0534	.0538	.0541	.0545	.0548	.0552	.0555
3.2	.0559	.0562	.0566	.0569	.0573	.0576	.0580	.0583	.0587	.0590
3.3	.0594	.0598	.0601	.0605	.0608	.0612	.0616	.0619	.0623	.0627
3.4	.0631	.0634	0638	.0642	.0645	.0649	.0653	.0657	.0661	.0664
3.5	.0668	.0672	.0676	.0680	.0684	.0687	.0691	.0695	.0699	.0703
3.6	.0707	.0711	.0715	.0719	.0723	.0727	.0731	.0735	.0739	.0743
3.7	.0747	.0751	.0755	.0759	.0763	.0767	.0771	.0775	.0779	.0783
3.8	.0788	.0792	.0796	.0800	.0804	.0808	.0813	.0817	.0821	.0825
3.9	0830	.0834	.0838	.0842	.0847	.0851	.0855	.0860	.0864	.0868
					4.00—4.99 Inches D.B.H.					
4.0	.0873	.0877	.0881	.0886	.0890	.0895	.0899	.0904	.0908	.0912
4.1	.0912	.0921	.0926	.0930	.0935	.0939	.0944	.0948	.0953	.0958
4.2	.0962	.0967	0971	.0976	.0981	.0985	.0990	.0995	.0999	.1004
4.3	.1008	.1013	.1018	.1023	.1027	.1032	.1032	.1042	.1046	.1051
4.4	.1056	.1061	.1066	.1070	.1075	.1080	.1085	.1090	.1095	.1100
4.5	.1104	.1109	.1114	.1119	.1124	.1129	.1134	.1139	.1144	.1149
4.6	.1154	.1159	.1164	.1169	.1171	.1179	.1184	.1190	.1195	.1200
4.7	.1205	.1210	.1215	.1220	.1225	.1231	.1236	.1241	.1246	.1251
4.8	.1257	.1262	.1267	.1272	.1278	.1283	.1288	.1294	.1299	.1304
4.9	.1310	.1315	.1320	.1326	.1331	.1336	.1342	.1347	.1353	.1358
					5.00—5.99 Inches D.B.H.					
5.0	.1364	.1369	.1375	.1380	.1385	.1391	.1397	.1402	.1408	.1413
5.1	.1419	.1424	.1430	.1435	.1441	.1447	.1452	.1458	.1464	.1469
5.2	.1475	.1481	.1486	.1492	.1498	.1503	.1509	.1515	.1521	.1526
5.3	.1532	.1538	.1544	.1550	.1555	.1561	.1567	.1573	.1579	.1585
5.4	.1590	.1596	.1602	.1608	.1614	.1620	.1626	.1632	.1638	.1644
5.5	.1650	.1656	.1662	.1668	.1674	.1680	.1686	.1692	.1698	.1704
5.6	.1710	.1717	.1723	.1729	.1735	.1741	.1747	.1754	.1760	.1766
5.7	.1772	.1778	.1785	.1791	.1797	.1803	.1810	.1816	.1822	.1829
5.8	.1835	.1841	.1848	.1854	.1860	.1867	.1873	.1879	.1886	.1892
5.9	.1899	.1905	.1912	.1918	.1924	.1931	.1937	.1944	.1950	.1957

Basal Area in Square Feet

D.B.H.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
					6.00—6.99 Inches D.B.H.					
inches										
6.0	.1964	.1970	.1977	.1983	.1990	.1996	.2003	.2010	.2016	.2023
6.1	.2030	.2036	.2043	.2050	.2056	.2063	.2070	.2076	.2083	.2090
6.2	.2097	.2103	.2110	.2117	.2124	.2131	.2137	.2144	.2151	.2158
6.3	.2165	.2172	.2179	.2185	.2192	.2199	.2206	.2213	.2220	.2227
6.4	.2234	.2241	.2248	.2250	.2262	.2269	.2276	.2283	.2290	.2297
6.5	.2304	.2312	.2319	.2326	.2333	.2340	.2347	.2354	.2362	.2369
6.6	.2376	.2383	.2390	.2398	.2405	.2412	.2419	.2427	.2434	.2441
6.7	.2448	.2456	.2463	.2470	.2478	.2485	.2492	.2550	.2507	.2515
6.8	.2522	.2529	.2537	.2544	.2552	.2559	.2567	.2574	.2582	.2589
6.9	.2597	.2604	.2612	.2619	.2627	.2635	.2642	.2650	.2657	.2665
					7.00—7.99 Inches D.B.H.					
7.0	.2673	.2680	.2688	.2696	.2703	.2711	.2719	.2726	.2734	.2742
7.1	.2749	.2757	.2765	.2773	.2781	.2788	.2796	.2804	.2812	.2820
7.2	.2827	.2835	.2843	.2851	.2859	.2867	.2875	.2883	.2891	.2897
7.3	.2907	.2915	.2923	.2931	.2939	.2947	.2955	.2963	.2971	.2979
7.4	.2987	.2995	.3003	.3011	.3019	.3027	.3035	.3044	.3052	.3060
7.5	.3068	.3076	.3084	.3093	.3101	.3109	.3117	.3126	.3134	.3142
7.6	.3150	.3159	.3167	.3175	.3184	.3192	.3200	.3209	.3217	.3225
7.7	.3234	.3242	.3251	.3259	.3268	.3276	.3842	.3293	.3301	.3310
7.8	.3318	.3327	.3335	.3344	.3352	.3361	.3370	.3378	.3387	.3395
7.9	.3404	.3413	.3421	.3430	.34[illegible]9	.3447	.3456	.3465	.3473	.3482
					8.00—8.99 Inches D B.H.					
8.0	.3491	.3499	.3508	.3517	.3526	.3534	.3543	.3552	.3561	.3570
8.1	.3579	.3587	.3596	.3605	.3614	.3623	.3632	.3641	.3650	.3658
8.2	.3667	.3676	.3685	.3694	.3703	.3712	.3721	.3730	.3739	.3748
8.3	.3757	.3766	.3776	.3785	.3794	.3803	.3712	.3821	.3830	.3839
8.4	.3849	.3858	.3867	.3876	.3885	.3894	.3904	.3913	.3922	.3931
8.5	.3941	.3950	.3959	.3968	.3978	.3987	.3997	.4006	.4015	.4025
8.6	.4034	.4043	.4053	.4062	.4072	.4081	.4090	.4100	.4109	.4119
8.7	.4128	.4138	.4147	.4157	.4166	.4176	.4185	.4195	.4205	.4214
8.8	.4224	.4233	.4243	.4253	.4262	.6272	.4282	.4291	.4301	.4311
8.9	.4320	.4330	.4340	.4349	.4359	.4369	.4379	.4389	.4398	.4408
					9.00—9.99 Inches D.B.H.					
9.0	.4418	.4428	.4438	.4447	.4457	.4467	.4477	.4487	.4497	.4507
9.1	.4517	.4527	.4537	.4546	.4556	.4566	.4576	.4586	.4596	.4606
9.2	.4616	.4626	.4637	.4647	.4657	.4667	.4677	.4687	.4697	.4707
9.3	.4717	.4728	.4738	.4748	.4758	.4768	.4778	.4789	.4799	.4809
9.4	.4819	.4830	.4840	.4850	.4860	.4871	.4881	.4891	.4902	.4912
9.5	.4922	.4933	.4943	.4954	.4964	.4974	.4985	.4995	.5006	.5016
9.6	.5027	.5037	.5048	.5058	.5069	.5079	.5090	.5100	.5111	.5121
9.7	.5132	.5142	.5153	.5164	.5174	.5185	.5196	.5206	.5217	.5228
9.8	.5238	.5249	.5260	.5270	.5281	.5292	.5303	.5313	.5324	.5335
9.9	.5346	.5356	.5367	.5378	.5389	.5400	.5411	.5422	.5432	.5443

Basal Area in Square Feet

D.B.H.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
					10.00—10.99 Inches D.B.H.					
inches										
10.0	.5454	.5466	.5477	.5488	.5499	.5510	.5520	.5531	.5542	.5553
10.1	.5564	.5575	.5586	.5597	.5608	.5620	.5631	.5641	.5652	.5664
10.2	.5675	.5687	.5698	.5708	.5720	.5730	.5742	.5753	.5765	.5776
10.3	.5786	.5799	.5809	.5820	.5831	.5842	.5853	.5866	.5876	.5886
10.4	.5899	.5910	.5921	.5932	.5944	.5956	.5967	.5977	.5990	.6001
10.5	.6013	.6023	.6035	.6047	.6058	.6070	.6082	.6093	.6105	.6117
10.6	.6128	.6140	.6151	.6162	.6174	.6186	.6198	.6209	.6220	.6233
10.7	.6244	.6257	.6270	.6282	.6293	.6305	.6318	.6328	.6340	.6352
10.8	.6362	.6376	.6386	.6398	.6409	.6420	.6433	.6445	.6456	.6468
10.9	.6480	.6492	.6503	.6515	.6528	.6539	.6551	.6562	.6575	.6586
					11.00—11.99 Inches D.B.H.					
11.0	.6600	.6612	.6626	.6637	.6648	.6660	.6671	.6683	.6695	.6707
11.1	.6720	.6731	.6743	.6755	.6768	.6780	.6792	.6803	.6816	.6828
11.2	.6841	.6853	.6866	.6879	.6890	.6901	.6915	.6927	.6940	.6951
11.3	.6964	.6876	.6990	.7002	.7013	.7026	.7039	.7050	.7062	.7075
11.4	.7088	.7099	.7111	.7123	.7137	.7149	.7161	.7173	.7187	.7200
11.5	.7213	.7224	.7236	.7249	.7262	.7275	.7287	.7300	.7313	.7325
11.6	.7339	.7350	.7363	.7377	.7389	.7401	.7413	.7427	.7439	.7451
11.7	.7466	.7477	.7490	.7503	.7515	.7528	.7541	.7554	.7567	.7579
11.8	.7594	.7606	.7619	.7633	.7646	.7659	.7671	.7684	.7692	.7710
11.9	.7723	.7736	.7749	.7762	.7774	.7789	.7800	.7814	.7828	.7840
					12.00—12.99 Inches D.B.H.					
12.0	.7854	.7869	.7881	.7894	.7907	.7920	.7933	.7947	.7960	.7972
12.1	.7985	.8000	.8013	.8027	.8040	.8051	.8067	.8079	.8092	.8105
12.2	.8118	.8130	.8143	.8157	.8170	.8185	.8199	.8210	.8224	.8237
12.3	.8252	.8264	.8278	.8292	.8305	.8319	.8331	.8344	.8358	.8370
12.4	.8386	.8400	.8413	.8427	.8440	.8453	.8469	.8481	.8495	.8509
12.5	.8522	.8536	.8550	.8563	.8577	.8590	.8603	.8617	.8630	.8644
12.6	.8659	.8671	.8686	.8700	.8714	.8727	.8740	.8754	.8768	.8781
12.7	.8797	.8810	.8824	.8838	.8852	.8865	.8880	.8893	.8907	.8920
12.8	.8936	.8950	.8963	.8977	.8990	.9005	.9019	.9033	.9048	.9061
12.9	.9076	.9090	.9014	.9119	.9132	.9147	.9160	.9173	.9189	.9204
					13.00—13.99 Inches D.B.H.					
13.0	.9217	.9231	.9246	.9260	.9274	.9288	.9303	.9317	.9331	.9345
13.1	.9360	.9374	.9388	.9403	.9417	.9431	.9446	.9460	.9474	.9489
13.2	.9503	.9517	.9532	.9546	.9561	.9575	.9590	.9604	.9619	.9633
13.3	.9648	.9662	.9677	.9691	.9706	.9720	.9735	.9749	.9764	.9779
13.4	.9793	.9808	.9822	.9837	.9852	.9866	.9881	.9896	.9910	.9925
13.5	.9940	.9955	.9964	.9984	.9999	1.0014	1.0028	1.0043	1.0058	1.0073
13.6	1.0088	1.0103	1.0117	1.0132	1.0147	1.0162	1.0177	1.0192	1.0207	1.0222
13.7	1.0237	1.0252	1.0267	1.0281	1.0296	1.0311	1.0326	1.0341	1.0356	1.0372
13.8	1.0387	1.0402	1.0417	1.0432	1.0447	1.0462	1.0477	1.0492	1.0507	1.0523
13.9	1.0538	1.0553	1.0568	1.0583	1.0598	1.0614	1.0629	1.0644	1.0659	1.0675

D.B.H.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
					14.00—14.99 INCHES D.B.H.					
inches										
14.0	1.0690	1.0705	1.0720	1.0736	1.0751	1.0766	1.0782	1.0797	1.0812	1.0828
14.1	1.0843	1.0858	1.0874	1.0889	1.0905	1.0920	1.0936	1.0951	1.0966	1.0982
14.2	1.0997	1.1013	1.1028	1.1044	1.1060	1.1075	1.1091	1.1106	1.1122	1.1137
14.3	1.1153	1.1168	1.1184	1.1200	1.1215	1.1231	1.1247	1.1262	1.1278	1.1294
14.4	1.1309	1.1325	1.1341	1.1357	1.1372	1.1388	1.1404	1.1420	1.1435	1.1451
14.5	1.1467	1.1483	1.1499	1.1515	1.1530	1.1546	1.1562	1.1578	1.1594	1.1610
14.6	1.1626	1.1642	1.1658	1.1674	1.1690	1.1706	1.1722	1.1737	1.1753	1.1770
14.7	1.1786	1.1802	1.1818	1.1834	1.1850	1.1866	1.1882	1.1898	1.1914	1.1930
14.8	1.1946	1.1963	1.1979	1.1995	1.2011	1.2027	1.2043	1.2060	1.2076	1.2092
14.9	1.2108	1.2125	1.2141	1.2157	1.2174	1.2190	1.2206	1.2222	1.2239	1.2255
					15.00—15.99 INCHES D.B.H.					
15.0	1.2272	1.2288	1.2304	1.2321	1.2331	1.2353	1.2370	1.2386	1.2403	1.2419
15.1	1.2436	1.2452	1.2469	1.2485	1.2502	1.2518	1.2535	1.2551	1.2568	1.2584
15.2	1.2601	1.2618	1.2634	1.2651	1.2667	1.2684	1.2701	1.2717	1.2734	1.2751
15.3	1.2767	1.2784	1.2801	1.2817	1.2834	1.2851	1.2867	1.2884	1.2901	1.2918
15.4	1.2935	1.2952	1.2968	1.2995	1.3002	1.3019	1.3036	1.3053	1.3069	1.3086
15.5	1.3103	1.3120	1.3137	1.3154	1.3171	1.3188	1.3205	1.3222	1.3239	1.3256
15.6	1.3273	1.3290	1.3307	1.3324	1.3341	1.3358	1.3375	1.3392	1.3409	1.3426
15.7	1.3444	1.3461	1.3478	1.3495	1.3512	1.3529	1.3547	1.3564	1.3581	1.3598
15.8	1.3615	1.3633	1.3650	1.3667	1.3684	1.3702	1.3719	1.3736	1.3754	1,3771
15.9	1.3788	1.3806	1.3823	1.3840	1.3858	1.3875	1.3893	1.3910	1.3927	1.3945
					16.00—16.99 INCHES D.B.H.					
16.0	1.3962	1.3980	1.3997	1.4015	1.4032	1.4050	1.4067	1.4085	1.4102	1.4120
16.1	1.4137	1.4155	1.4172	1.4190	1.4205	1.4225	1.4243	1.4261	1.4278	1.4296
16.2	1.4313	1.4331	1.4349	1.4367	1.4384	1.4402	1.4420	1.4437	1.4455	1.4473
16.3	1.4491	1.4509	1.4526	1.4544	1.4562	1.4580	1.4598	1.4615	1.4633	1.4651
16.4	1.4669	1.4687	1.4705	1.4723	1.4741	1.4759	1.4777	1.4795	1.4813	1.4832
16.5	1.4849	1.4867	1.4885	1.4903	1.4921	1.4939	1.4957	1.4975	1.4993	1.5011
16.6	1.5029	1.5047	1.5065	1.5083	1.5102	1.5120	1.5138	1.5156	1.5174	1.5192
16.7	1.5211	1.5229	1.5247	1.5265	1.5284	1.5302	1.5320	1.5338	1.5357	1.5377
16.8	1.5393	1.5412	1.5430	1.5448	1.5467	1.5485	1.5504	1.5522	1.5540	1.5559
16.9	1.5577	1.5596	1.5614	1.5633	1.5651	1.5669	1.5688	1.5706	1.5725	1.5744
					17.00—17.99 INCHES D.B.H.					
17.0	1.5762	1.5781	1.5800	1.5818	1.5836	1.5855	1.5874	1.5892	1.5911	1.5929
17.1	1.5948	1.5967	1.5985	1.6004	1.6023	1.6041	1.6060	1.6079	1.6098	1.6116
17.2	1.6135	1.6154	1.6173	1.6191	1.6210	1.6229	1.6248	1.6267	1.6286	1.6304
17.3	1.6323	1.6342	1.6361	1.6380	1.6399	1.6418	1.6437	1.6456	1.6475	1.6494
17.4	1.6513	1.6531	1.6550	1.6570	1.6589	1.6608	1.6627	1.6646	1.6665	1.6689
17.5	1.6703	1.6722	1.6741	1.6760	1.6780	1.6798	1.6818	1.6837	1.6856	1.6875
17.6	1.6894	1.6914	1.6933	1.6952	1.6979	1.6990	1.7010	1.7029	1.7048	1.7068
17.7	1.7087	1.7106	1.7125	1.7145	1.7164	1.7184	1.7203	1.7222	1.7242	1.7261
17.8	1.7280	1.7300	1.7319	1.7339	1.7358	1.7378	1.7397	1.7417	1.7436	1.7456
17.9	1.7475	1.7495	1.7514	1.7534	1.7553	1.7573	1.7593	1.7612	1.7631	1.7651

D.B.H.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
					18.00—18.99 Inches D.B.H.					
inches										
18.0	1.7671	1.7691	1.7710	1.7730	1.7750	1.7769	1.7789	1.7809	1.7828	1.7848
18.1	1.7868	1.7888	1.7908	1.7927	1.7947	1.7967	1.7987	1.8006	1.8026	1.8046
18.2	1.8066	1.8086	1.8106	1.8125	1.8145	1.8165	1.8185	1.8205	1.8225	1.8245
18.3	1.8265	1.8285	1.8305	1.8325	1.8345	1.8365	1.8385	1.8405	1.8425	1.8445
18.4	1.8465	1.8485	1.8505	1.8525	1.8545	1.8566	1.8586	1.8606	1.8626	1.8646
18.5	1.8666	1.8686	1.8707	1.8727	1.8747	1.8767	1.8788	1.8808	1.8828	1.8848
18.6	1.8869	1.8889	1.8909	1.8930	1.8950	1.8970	1.8991	1.9011	1.9031	1.9052
18.7	1.9072	1.9092	1.9113	1.9133	1.9154	1.9174	1.9195	1.9215	1.9236	1.9256
18.8	1.9277	1.9297	1.9318	1.9338	1.9359	1.9379	1.9400	1.9420	1.9441	1.9462
18.9	1.9482	1.9503	1.9523	1.9544	1.9565	1.9585	1.9606	1.9627	1.9647	1.9669
					19.00—19.99 Inches D.B.H.					
19.0	1.9689	1.9710	1.9730	1.9751	1.9772	1.9793	1.9814	1.9833	1.9855	1.9876
19.1	1.9897	1.9918	1.9938	1.9959	1.9980	2.0001	2.0022	2.0043	2.0064	2.0085
19.2	2.0106	2.0127	2.0418	2.0169	2.0190	2.0211	2.0232	2.0253	2.0273	2.0295
19.3	2.0316	2.0337	2.0358	2.0379	2.0400	2.0421	2.0442	2.0463	2.0484	2.0506
19.4	2.0527	2.0548	2.0569	2.0590	2.0611	2.0633	2.0654	2.0675	2.0696	2.0718
19.5	2.0739	2.0760	2.0781	2.0803	2.0824	2.0845	2.0867	2.0888	2.0909	2.0931
19.6	2.0952	2.0973	2.0995	2.1016	2.1038	2.1059	2.1081	2.1102	2.1123	2.1145
19.7	2.1166	2.1188	2.1209	2.1231	2.1252	2.1274	2.1296	2.1317	2.1339	2.1360
19.8	2.1382	2.1403	2.1425	2.1447	2.1468	2.1490	2.1512	2.1533	2.1555	2.1577
19.9	2.1598	2.1620	2.1642	2.1668	2.1685	2.1707	2.1729	2.1751	2.1772	2.1794
					20.00—20.99 Inches D.B.H.					
20.0	2.1816	2.1838	2.1860	2.1882	2.1903	2.1925	2.1947	2.1969	2.1991	2.2013
20.1	2.2035	2.2057	2.2079	2.2101	2.2123	2.2144	2.2166	2.2188	2.2210	2.2232
20.2	2.2255	2.2277	2.2299	2.2321	2.2343	2.2365	2.2387	2.2409	2.2431	2.2453
20.3	2.2475	2.2498	2.2520	2.2542	2.2564	2.2586	2.2608	2.2631	2.2653	2.2675
21.4	2.4977	2.5000	2.5024	2.5047	2.5071	2.5094	2.5117	2.5141	2.5164	2.5188
20.5	2.2920	2.2943	2.2965	2.2988	2.3010	2.3032	2.3055	2.3077	2.3100	2.3122
20.6	2.3145	2.3167	2.3190	2.3212	2.3235	2.3257	2.3280	2.3302	2.3325	2.3347
20.7	2.3370	2.3392	2.3415	2.3438	2.3460	2.3483	2.3506	2.3528	2.3551	2.3573
20.8	2.3596	2.3619	2.3642	2.3664	2.3687	2.3709	2.3733	2.3755	2.3778	2.3801
20.9	2.3824	2.3846	2.3869	2.3892	2.3915	2.3938	2.3961	2.3983	2.4006	2.4029
					21.00—21.99 Inches D.B.H.					
21.0	2.4052	2.4675	2.4098	2.4121	2.4144	2.4167	2.4190	2.4213	2.4236	2.4259
21.1	2.4282	2.4305	2.4328	2.4351	2.4374	2.4397	2.4420	2.4443	2.4466	2.4489
21.2	2.4512	2.4536	2.4559	2.4582	2.4605	2.4628	2.4651	2.4675	2.4698	2.4721
21.3	2.4744	2.4767	2.4791	2.4814	2.4837	2.4861	2.4884	2.4907	2.4930	2.4954
21.4	2.4877	2.5000	2.5024	2.5047	2.5071	2.5094	2.5117	2.5141	2.5164	2.5188
21.5	2.5211	2.5235	2.5258	2.5282	2.5305	2.5328	2.5352	2.5376	2.5399	2.5423
21.6	2.5446	2.5470	2.5493	2.5517	2.5540	2.5564	2.5588	2.5611	2.5635	2.5659
21.7	2.5682	2.5706	2.5730	2.5753	2.5777	2.5801	2.5825	2.5848	2.5877	2.5896
21.8	2.5920	2.5943	2.5967	2.5991	2.6015	2.6039	2.6062	2.6086	2.6110	2.6134
21.9	2.6158	2.6182	2.6206	2.6230	2.6254	2.6278	2.6301	2.6325	2.6349	2.6373

D.B.H.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
					22.00—22.99 INCHES D.B.H.					
inches										
22.0	2.6397	2.6421	2.6445	2.6469	2.6493	2.6519	2.6542	2.6566	2.6590	2.6614
22.1	2.6638	2.6662	2.6686	2.6710	2.6734	2.6759	2.6783	2.6807	2.6831	2.6855
22.2	2.6879	2.6904	2.6928	2.6952	2.6976	2.7001	2.7025	2.7049	2.7074	2.7098
22.3	2.7122	2.7147	2.7171	2.7195	2.7220	2.7244	2.7268	2.7293	2.7317	2.7342
22.4	2.7366	2.7383	2.7415	2.7439	2.7464	2.7488	2.7513	2.7537	2.7562	2.7586
22.5	2.7611	2.7635	2.7660	2.7685	2.7709	2.7734	2.7758	2.7783	2.7807	2.7832
22.6	2.7857	2.7881	2.7906	2.7931	2.7956	2.7980	2.8005	2.8030	2.8054	2.8079
22.7	2.8104	2.8129	2.8153	2.8178	2.8203	2.8228	2.8253	2.8278	2.8302	2.8327
22.8	2.8352	2.8377	2.8402	2.8427	2.8452	2.8477	2.8502	2.8526	2.8551	2.8576
22.9	2.8601	2.8626	2.8651	2.8676	2.8701	2.8726	2.8751	2.8776	2.8801	2.8827
					23.00—23.99 INCHES D.B.H.					
23.0	2.8852	2.8877	2.8902	2.8927	2.8952	2.8977	2.9002	2.9028	2.9053	2.9078
23.1	2.9103	2.9128	2.9153	2.9179	2.9204	2.9229	2.9254	2.9280	2.9305	2.9330
23.2	2.9356	2.9381	2.9406	2.9432	2.9457	2.9482	2.9508	2.9533	2.9558	2.9584
23.3	2.9609	2.9635	2.9660	2.9686	2.9711	2.9736	2.9762	2.9787	2.9813	2.9838
23.4	2.9864	2.9889	2.9915	2.9941	2.9966	2.9992	3.0017	3.0043	3.0069	3.0094
23.5	3.0120	3.0145	3.0171	3.0197	3.0222	3.0248	3.0274	3.0299	3.0325	3.0351
23.6	3.0377	3.0402	3.0428	3.0454	3.0480	3.0505	3.0531	3.0557	3.0583	3.0609
23.7	3.0635	3.0660	3.0686	3.0712	3.0738	3.0764	3.0790	3.0816	3.0842	3.0868
23.8	3.0894	3.0920	3.0946	3.0972	3.0998	3.1024	3.1050	3.1076	3.1102	3.1128
23.9	3.1154	3.1180	3.1206	3.1232	3.1258	3.1284	3.1310	3.1337	3.1363	3.1389
					24.00—24.99 INCHES D.B.H.					
24.0	3.1415	3.1441	3.1467	3.1494	3.1520	3.1546	3.1572	3.1599	3.1625	3.1651
24.1	3.1677	3.1704	3.1730	3.1756	3.1783	3.1809	3.1835	3.1862	3.1888	3.1914
24.2	3.1941	3.1967	3.1994	3.2020	3.2047	3.2072	3.2099	3.2126	3.2152	3.2179
24.3	3.2205	3.2233	3.2258	3.2285	3.2311	3.2338	3.2365	3.2395	3.2418	3.2444
24.4	3.2471	3.2498	3.2524	3.2551	3.2577	3.2604	3.2631	3.2657	3.2684	3.2711
24.5	3.2738	3.2764	3.2791	3.2818	3.2839	3.2871	3.2898	3.2925	3.2952	3.2979
24.6	3.3005	3.3032	3.3059	3.3086	3.3113	3.3140	3.3167	3.3194	3.3220	3.3247
24.7	3.3274	3.3301	3.3328	3.3355	3.3382	3.3409	3.3436	3.3463	3.3490	3.3517
24.8	3.3544	3.3571	3.3598	3.3625	3.3653	3.3680	3.3707	3.3734	3.3761	3.3788
24.9	3.3815	3.3843	3.3869	3.3897	3.3924	3.3951	3.3978	3.4006	3.4033	3.4060
					25.00—25.99 INCHES D.B.H.					
25.0	3.4087	3.4105	3.4142	3.4169	3.4192	3.4224	3.4251	3.4279	3.4306	3.4333
25.1	3.4361	3.4388	3.4416	3.4443	3.4470	3.4498	3.4525	3.4553	3.4580	3.4608
25.2	3.4635	3.4663	3.4690	3.4718	3.4745	3.4773	3.4800	3.4828	3.4855	3.4883
25.3	3.4911	3.4938	3.4966	3.4993	3.5021	3.5049	3.5076	3.5104	3.5132	3.5159
25.4	3.5187	3.5215	3.5242	3.5270	3.5298	3.5326	3.5353	3.5381	3.5409	3.5437
25.5	3.5465	3.5492	3.5520	3.5548	3.5576	3.5604	3.5632	3.5660	3.5687	3.5715
25.6	3.5743	3.5771	3.5799	3.5827	3.5855	3.5883	3.5911	3.5939	3.5967	3.5995
25.7	3.6023	3.6051	3.6079	3.6107	3.6135	3.6163	3.6192	3.6220	3.6248	3.6276
25.8	3.6304	3.6332	3.6360	3.6388	3.6417	3.6444	3.6473	3.6501	3.6529	3.6558
25.9	3.6586	3.6614	3.6642	3.6671	3.6699	3.6727	3.6756	3.6784	3.6812	3.6841

D.B.H.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
					26.00—26.99 Inches D.B.H.					
inches										
26.0	3.6869	3.6897	3.6926	3.6954	3.6983	3.7011	3.7039	3.7068	3.7096	3.7125
26.1	3.7153	3.7182	3.7210	3.7239	3.7267	3.7296	3.7324	3.7353	3.7381	3.7410
26.2	3.7438	3.7467	3.7496	3.7524	3.7553	3.7581	3.7610	3.7639	3.7668	3.7696
26.3	3.7725	3.7753	3.7782	3.7811	3.7840	3.7868	3.7897	3.7926	3.7955	3.7983
26.4	3.8012	3.8041	3.8070	3.8099	3.8127	3.8156	3.8185	3.8214	3.8243	3.8272
26.5	3.8301	3.8330	3.8359	3.8387	3.8416	3.8445	3.8474	3.8503	3.8532	3.8561
26.6	3.8590	3.8619	3.8648	3.8677	3.8706	3.8736	3.8765	3.8794	3.8823	3.8852
26.7	3.8881	3.8910	3.8939	3.8968	3.8998	3.9027	3.9056	3.9085	3.9114	3.9144
26.8	3.9173	3.9202	3.9231	3.9261	3.9290	3.9319	3.9348	3.9378	3.9407	3.9436
26.9	3.9466	3.9495	3.9524	3.9554	3.9583	3.9613	3.9642	3.9671	3.9701	3.9730
					27.00—27.99 Inches D.B.H.					
27.0	3.9760	3.9789	3.9819	3.9848	3.9878	3.9907	3.9937	3.9966	3.9996	4.0025
27.1	4.0055	4.0084	4.0114	4.0143	4.0173	4.0203	4.0232	4.0262	4.0292	4.0321
27.2	4.0351	4.0381	4.0410	4.0440	4.0470	4.0499	4.0529	4.0559	4.0589	4.0618
27.3	4.0648	4,0678	4.0708	4.0738	4.0767	4.0797	4.0827	4.0857	4.0887	4.0917
27.4	4.0946	4.0976	4.1006	4.1036	4.1066	4.1096	4.1126	4.1156	4.1186	4.1216
27.5	4.1246	4.1276	4.1306	4.1336	4.1366	4.1396	4.1426	4.1456	4.1486	4.1516
27.6	4.1546	4.1576	4.1607	4.1637	4.1667	4.1697	4.1727	4.1757	4.1788	4.1818
27.7	4.1848	4.1878	4.1908	4.1939	4.1969	4.1999	4.2030	4.2060	4.2090	4.2120
27.8	4.2151	4.2181	4.2211	4.2242	4.2272	4.2302	4.2333	4.2363	4.2394	4.2424
27 9	4.2464	4.2485	4.2515	4.2546	4.2576	4.2607	4.2637	4.2668	4.2698	4.2729